NRD RESOURCE ROOM
121854
BITH
office copy

A SUMMARY OF WATER QUALITY FOR THE BIG SANDY CREEK UNIT, BEECH CREEK UNIT, AND TURKEY CREEK UNIT OF BIG THICKET NATIONAL PRESERVE, TEXAS (1975-1981)

TECHNICAL REPORT NO. 85-BITH-1

WATER RESOURCES DIVISION
NATIONAL PARK SERVICE
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO 80523

This report presents the results of a study conducted by the National Park Service Water Resources Division. It is intended primarily for use by the particular Park Service area or areas that are addressed in the report but may be of interest to other persons working in water resources management. Requests for copies of this report should be addressed to:

Chief
Water Resources Division
National Park Service
301 South Howes Street
Fort Collins, Colorado 80521

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

A SUMMARY OF WATER QUALITY FOR THE BIG SANDY CREEK UNIT, BEECH CREEK UNIT, AND TURKEY CREEK UNIT OF BIG THICKET NATIONAL PRESERVE, TEXAS (1975-1981)

TECHNICAL REPORT NO. 85-BITH-1

by

Mark D. Flora
Stephen J. Lawrence
Mary Cavendish

Applied Research Branch
Water Resources Division
National Park Service
Colorado State University
Fort Collins, Colorado 80523

April 1985

Digitized by the Internet Archive
in 2012 with funding from
LYRASIS Members and Sloan Foundation

http://archive.org/details/summaryofwaterqu00flor

ABSTRACT

The Big Thicket National Preserve (BITH) in southeastern Texas contains a diversity of water resources, including the lower Neches River, several major streams and smaller tributaries, and extensive floodplain forest, baygall, and cypress sloughs. Present land-use activities within the watershed of BITH, such as oil field development, timber harvesting, and residential development, may adversely influence the quality of the water entering the preserve.

This report synthesizes available water quality information for three Management Units—Big Sandy Creek, Beech Creek, and Turkey Creek—in Big Thicket National Preserve. From this information, water quality conditions during the 1970's can be established as a baseline to which results of current water quality monitoring may be compared. Physicochemical constituents, nutrient chemistry, bacteriological data, benthic macroinvertebrate diversity, and fish data were all considered in analyzing and establishing baseline conditions. These data are also used to document areas of existing and potential water quality concern in the three management units.

ACKNOWLEDGMENTS

The authors would like to thank a number of people who directly assisted in the completion of this report. Dr. Sam Kunkle of the National Park Service Water Resources Division lent valuable assistance in the conceptualization of this paper and in the design of Big Thicket National Preserve's monitoring program. Juliette Wilson (National Park Service/Colorado State University) completed the annotated bibliography in the Appendix and provided extensive editorial assistance.

Tom Lubbert, Jim Woods, and Bob Krumenaker of the Big Thicket staff not only provided valuable advice concerning the Preserve's needs and available data sources but were instrumental in the implementation of the recommended water quality monitoring program. Dr. Richard Harrel of Lamar University in Beaumont, Texas, and Chris Baumann of Big Thicket National Preserve rendered detailed and helpful review comments on the final manuscript.

Finally, we'd like to thank Hanae Akari and Kenneth Streeb, who drafted the illustrations for this report, and give special thanks to Sandy Page, Linda Jensen, and Liz Lambert of the Engineering Research Center technical typing staff for their diligence and patience.

TABLE OF CONTENTS

	Page
ABSTRACT	i
ACKNOWLEDGMENTS	ii
LIST OF FIGURES	iv
LIST OF TABLES	vii
INTRODUCTION	1
Physiography, Geology, and Climate	4
BIG SANDY CREEK UNIT	
General Description	6
Previous Studies	8
Water Quality Analysis	9
Physicochemical constituents	9
Nutrient chemistry	15
Biological Sampling	15
Conclusions	18
BEECH CREEK UNIT	
General Description	20
Previous Studies	22
Water Quality Analysis	22
Physicochemical constituents	22
Nutrient chemistry	27
Biological Sampling	30
Conclusions	31
TURKEY CREEK UNIT	
General Description	33
Previous Studies and Applicable State Standards	35
Water Quality Analysis	38
Physicochemical constituents	38
Nutrient chemistry	43
Biological Sampling	46
Conclusions	48
LITERATURE CITED	50
APPENDIX: ANNOTATED BIBLIOGRAPHY	52

LIST OF FIGURES

Figure		Page
1	Management Units of the Big Thicket National Preserve, Texas, with historical and proposed water quality monitoring sites	2
2	Vegetation map of Big Sandy Creek Unit with historic sampling sites	7
3	Sampling periods and parameters measured in the Big Sandy Creek Unit	10
4	Seasonal profile of water temperatures (1980-1981) for five sampling sites in the Big Sandy Creek Unit	10
5	Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1980-1981) for five sampling sites in the Big Sandy Creek Unit	11
6	Median and range of pH levels for sampling sites in the Big Sandy Creek Unit (1975-1981)	12
7	Median and range of alkalinity concentrations for sampling sites in the Big Sandy Creek Unit (1975-1981).	12
8	Low flow/high flow turbidity ranges for five sampling sites in the Big Sandy Creek Unit (1975-1981)	13
9	Median and range of specific conductance values for sampling sites in the Big Sandy Creek Unit (1975-1981)	14
10	Median and range of chloride concentrations for sampling sites in the Big Sandy Creek Unit (1975-1981)	14
11	The seasonal relationship of PO_4^{-3} and NH_4^+-N with flow regime for two sampling sites representing inputs (BS-1) and outputs (BS-5) to the Big Sandy Creek Unit (1980-1981)	16
12	A profile of fecal coliform and fecal streptococcus bacteria counts through the Big Sandy Creek Unit (1980-1981)	17
13	Annual percent distribution of aquatic macroinvertebrates and Shannon-Weaver diversity values for sampling sites of the Big Sandy Creek Unit (1980-1981)	18
14	Vegetation map of the Beech Creek Unit with historic sampling sites	21
15	Sampling periods and parameters measured in the Beech Creek Unit	23

Figure		Page
16	Seasonal profile of water temperatures (1976-1977) for the five sampling sites in the Beech Creek Unit . . .	24
17	Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1976-1977) for the five sampling sites in the Beech Creek Unit	24
18	Median and range of pH levels for sampling sites in the Beech Creek Unit (1975-1977)	25
19	Median and range of alkalinity concentrations for sampling sites in the Beech Creek Unit (1975-1977) . . .	26
20	Frequency of occurrence of color values for samples from the Beech Creek Unit (1975-1977)	26
21	Low flow/high flow turbidity ranges for five sampling sites in the Beech Creek Unit (1975-1977)	27
22	Median and range of specific conductance values for sampling sites in the Beech Creek Unit (1975-1977) . . .	28
23	Median and range of chloride concentrations for sampling sites in the Beech Creek Unit (1975-1977) . . .	28
24	The seasonal relationship of PO_4^{-3} and NO_3-N with discharge for two sampling sites representing inputs (BC-1) and outputs (BC-5) to the Beech Creek Unit (1976-1977)	29
25	Annual percent distribution of benthic macroinvertebrates and Shannon-Weaver diversity values for sampling sites of the Beech Creek Unit (1976-1977) . . .	30
26	Vegetation map of the Turkey Creek Unit with historic sampling sites	34
27	Sampling periods and parameters measured in the Turkey Creek Unit	37
28	Seasonal profile of water temperature (1979-1980) for the Turkey Creek and Hickory Creek stations in the Turkey Creek Unit	38
29	Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1979-1980) for the Turkey Creek and Hickory Creek sampling sites in the Turkey Creek Unit	39
30	Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1979-1980) for the Village Creek sites in the Turkey Creek Unit	40

Figure		Page
31	Median and range of pH levels for sampling sites in the Turkey Creek Unit (1975-1980)	41
32	Median and range of alkalinity concentrations for sampling sites in the Turkey Creek Unit (1975-1980) . . .	42
33	Frequency of occurrence of color values for samples from the Turkey Creek Unit (1975-1980)	42
34	Low flow/high flow turbidity ranges for seven sampling sites in the Turkey Creek Unit (1975-1980)	43
35	Median and range of specific conductance values for sampling sites in the Turkey Creek Unit (1975-1980) . . .	44
36	Median and range of chloride concentrations for sampling sites in the Turkey Creek Unit (1975-1980) . . .	44
37	Median and range of NH_4^+-N concentrations for sampling sites in the Turkey Creek Unit (1979-1980)	45
38	Median and range of PO_4^{-3} concentrations for sampling sites in the Turkey Creek Unit (1979-1980)	45
39	A profile of fecal coliform and fecal streptococcus bacteria counts through the Turkey Creek Unit (1979-1980)	47
40	Annual percent distribution of aquatic macroinvertebrates and Shannon-Weaver diversity values for some sampling sites in the Turkey Creek Unit (1979-1980) . . .	48

LIST OF TABLES

Table		Page
1	Locations of sampling sites within the Big Sandy Creek Unit with descriptions of stream bottom substrate . . .	9
2	Locations of sampling sites within the Beech Creek Unit with descriptions of stream bottom substrate . . .	23
3	Locations of sampling sites within the Turkey Creek Unit with descriptions of stream bottom substrate . . .	36

INTRODUCTION

Big Thicket National Preserve (BITH) in southeastern Texas comprises 34,217 ha (84,550 acres) of pine and cypress forest, hardwood forest, meadow, and blackwater swamp. The preserve was set aside in 1974 in order to "assure the preservation, conservation, and protection of the natural, scenic and recreational values of the Big Thicket area" (Public Law 93-439).

The preserve is composed of 12 distinct management units (Figure 1) located in portions of Hardin, Jasper, Jefferson, Liberty, Orange, Polk, and Tyler counties. The management units were selected to protect distinct areas that are representative of the ecological diversity of the Big Thicket region. The equally diverse water resources of the various units range from small tributaries to a major river. Development within and surrounding the units influence the quality of water within the streams of the preserve.

The following land-use activities influence the water quality of BITH:

1. oil field exploration and development in and adjacent to the preserve;
2. timber harvesting adjacent to several of the management units;
3. residential and recreational development, including subsequent production of sewage effluent along the periphery of the preserve.

Elevated concentrations of suspended sediment, chlorides, coliform bacteria, chlorine, nutrients, and turbidity in the water of the units downstream of these and other activities may lead to a subsequent decline in the ecological, aesthetic, and beneficial uses of the water.

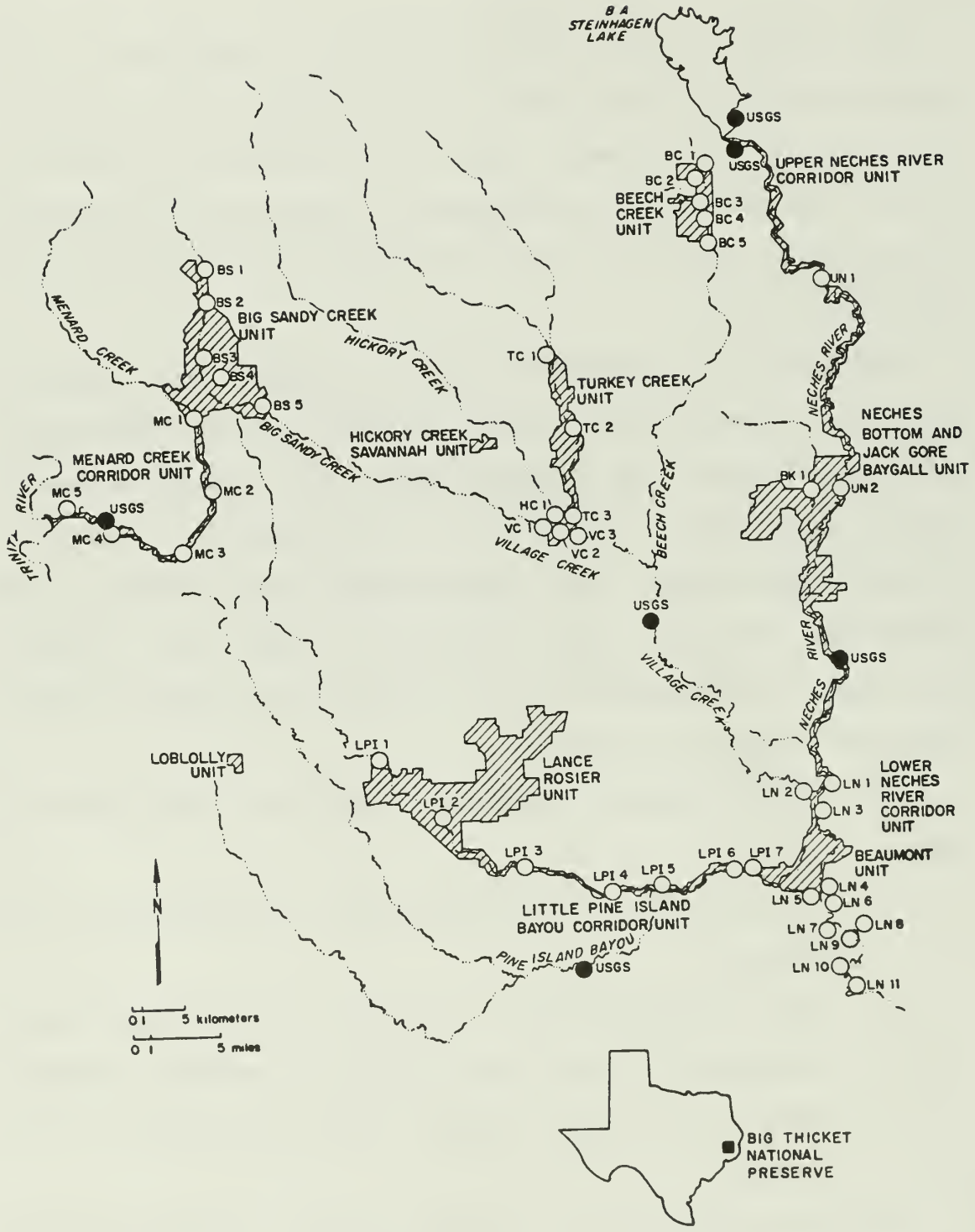

Figure 1. Management Units of the Big Thicket National Preserve, Texas, with historical and proposed water quality monitoring sites.

To assess the effects of these activities on the water resources of BITH, a water quality monitoring program was proposed in 1984. An early component of this plan is the documentation and summarization of available water quality information gained from previous environmental studies in the preserve. Beginning in 1975, a number of water quality/aquatic biology studies were conducted in Big Thicket National Preserve by Dr. Richard Harrel and students from Lamar University (see Harrel and Watson, 1975; Harrel, 1976; Harrel, 1977; Kost, 1977; Darville, 1978; Bass, 1979; Harrel and Bass, 1979; Harrel and Commander, 1980; Harrel and Newberry, 1981) with a number of other researchers providing specific information on regional hydrology, fish populations, and bacterial contamination. An annotated bibliography of these studies is presented in the Appendix.

Although of limited duration, these previous studies provide the resource management specialist with important information regarding the baseline water quality conditions in Big Thicket National Preserve during the late 1970s.

In this report, we compile water quality information available from the Big Sandy Creek, Beech Creek, and Turkey Creek units of Big Thicket National Preserve. Water quality information is presented for each of these three units individually. This will allow for a unit-by-unit comparison of data obtained from a water quality monitoring program implemented by National Park Service (NPS) personnel in the fall of 1984.

The format for this report begins with a general basin description that provides brief information on basin geology, soils, and vegetation. This is followed by a listing of previous aquatic studies completed within the unit. Data from each of these studies is then compiled on a

constituent-by-constituent basis and summarized. A variety of graphical techniques is used to enhance data interpretation of the compiled data base.

Physicochemical water quality constituents considered in this report include water temperature, dissolved oxygen, pH, alkalinity, turbidity, color, specific conductance, and chlorides. Nutrient chemistry data, when available, includes orthophosphate, ammonia, and nitrate. When available discharge data are sufficient, relationships between water quality constituent concentration and discharge are discussed.

Biological data, including information on bacteriological contamination, macroinvertebrates, and fish populations are also included. No attempts are made to use population indices in the interpretation of the biological data unless this was done in the original study.

Physiography, Geology, and Climate

Big Thicket National Preserve is located on the geologically young coastal plain of southeast Texas. Surface formations were deposited by streams as alluvial plains and deltas during interglacial periods of the Pleistocene and Holocene epochs (USDI, 1976). The upper part of the preserve is hilly and well-drained and is separated by the Hockley scarp from the low, flat, and poorly drained areas of the lower preserve.

The oldest formations occur in the upper Big Thicket area and include the Willis formation, which was laid down in the Pliocene epoch. The youngest formations occur in the lower Big Thicket area and include the Bentley, Montgomery, and Beaumont formations.

The soils development generally reflects differences in geology and drainage conditions within the preserve. Soils are predominantly well-drained sandy loams in the upper BITH area, noncalcareous loams with iron oxide concretions in the central BITH area, and clayey and poorly drained soils in the lower BITH area (USDI, 1976).

Because the preserve is located within 75 miles of the upper Texas Coast and the prevailing winds are southeasterly, the climate is strongly influenced by maritime air masses brought in from the Gulf of Mexico. As a result, hurricanes, tropical storms, and thunderstorms are common. During the winter and spring months, the weather is affected by continental air masses entering the area that are driven by frontal cyclones moving west to east across the U.S. (Trenchard, 1977). The majority of the rainfall occurs in the spring and summer months. Summers in the preserve are generally warm and humid with abundant rainfall provided by thunderstorms. Frequent flooding along the Neches and Trinity Rivers and their major tributaries maintains the floodplain vegetation along the bottomlands of these streams and rivers.

BIG SANDY CREEK UNIT

General Description

The Big Sandy Creek Management Unit comprises 5787 ha (14,300 acres) of the upper Big Thicket basin within Polk County, Texas. Big Sandy Creek and a small portion of Menard Creek flow through the unit, with the headwaters of these streams originating outside the Big Thicket National Preserve. Big Sandy Creek begins in northern Polk County and flows in a southeasterly direction, becoming Village Creek at the Hardin/Polk county line. The average gradient of Big Sandy Creek within the management unit is .53 m/km (1.08 ft/mi). A small tributary to Big Sandy Creek included in the sampling regime (BS-4) flows for 6.4 km (4.0 mi) before entering Big Sandy Creek (Figure 2). The average gradient of this tributary is 5.7 m/km (11.6 ft/mi) (Harrel and Newberry, 1981). At the time of the Harrel and Newberry study there were no known man-made impacts on the Big Sandy Creek other than those possibly coming from the Alabama-Coushatta Indian Reservation. However, increased oil and gas activity in the Indian Reservation and proposed activity within the Big Sandy Unit itself constitute a water quality concern.

Approximately 82 percent of the soils within the Big Sandy Unit are composed of the Bowie and Mantachie series (Deshotels, 1978). Soils of the Bowie series make up 64 percent of the unit. These soils are moderately well-drained and are characterized by a slow percolation rate. These soils are not subject to flooding, and the water table is generally lower than 1.83 m (6.0 ft) below the surface. These soils are only moderately erodible (Deshotels, 1978).

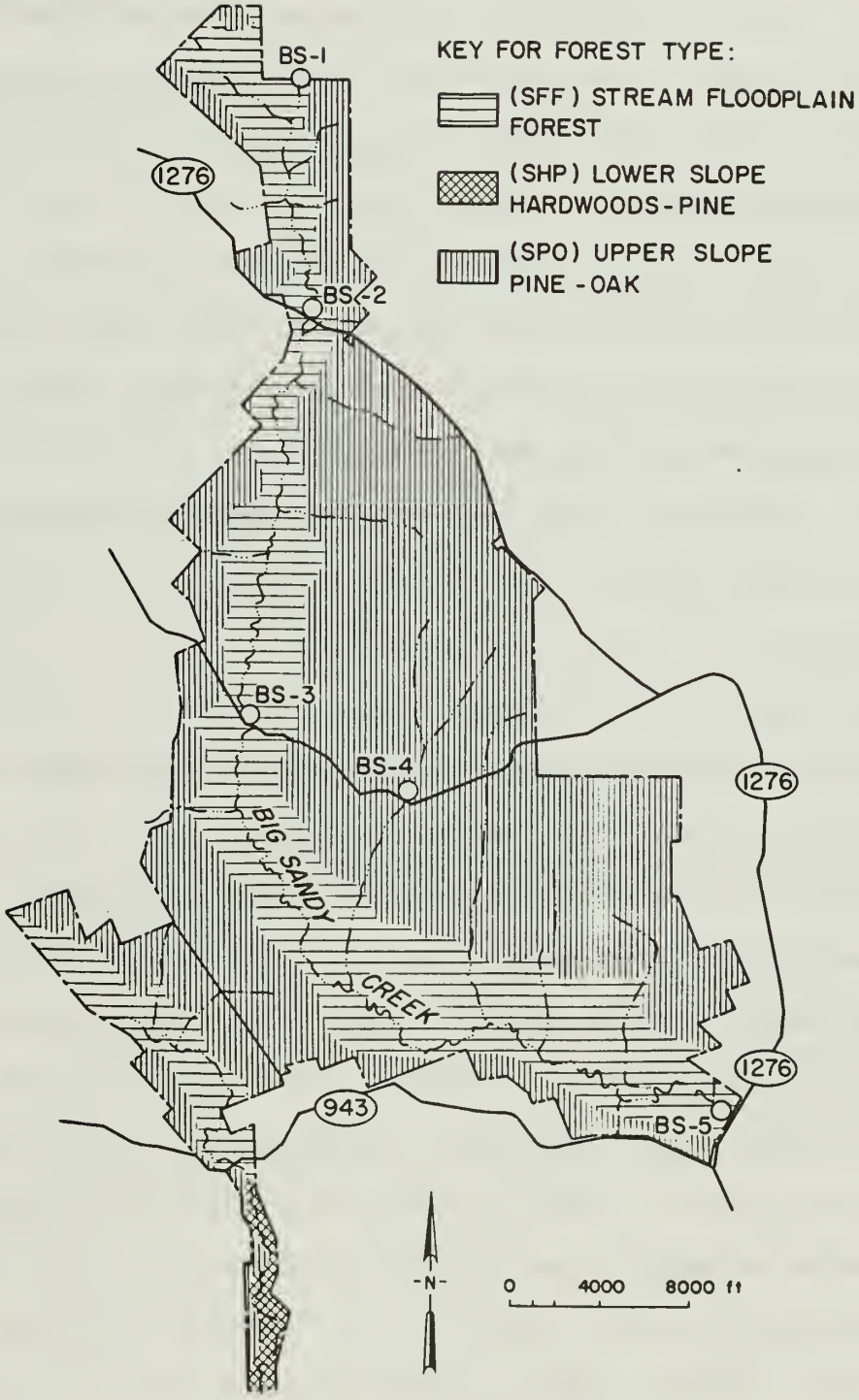

Figure 2. Vegetation map of Big Sandy Creek Unit and part of the Menard Creek Unit with historic sampling sites. Adapted from USDI (1976).

Soils of the Mantachie series compose about 18 percent of the Big Sandy Unit. These are floodplain soils adjacent to stream channels and are frequently flooded. The water table is high, especially during the winter when it ranges from .30 m to .45 m (1.0 to 1.5 ft) below the surface (Deshotels, 1978).

Three vegetation types (Figure 2) predominate in the Big Sandy Creek Unit. These are the stream floodplain forest, which includes bottomland hardwoods and acid bog-baygall associations; upper slope forest, which includes white oak, beech, magnolia, and loblolly pine associations; and upland forest, which includes shortleaf, longleaf, and loblolly pine (USDI, 1976).

Previous Studies

Harrel (1976) first measured physicochemical water quality parameters in the Big Sandy Unit as part of a reconnaissance water quality study undertaken in BITH during the summer of 1975. The purpose of this study was to establish stations for future water quality monitoring. Additional physicochemical and biological data were obtained during the summer of 1976 (Harrel, 1977) in a study conducted to (1) locate sites of existing or potential pollution, (2) determine downstream trends, and (3) develop recommendations for management throughout the preserve. Harrel and Darville (1978) collected physicochemical and bacteriological data in Big Sandy Creek as part of a larger study undertaken during the summer of 1977. In 1980-1981, Harrel and Newberry (1981) conducted the first full-year study within the unit and provided extensive physicochemical, bacteriological, and benthic macroinvertebrate data. Big Sandy Creek was also included in the Big Thicket fish survey (Suttkus and Clemmer, 1979). Sampling periods and

parameters sampled in these studies are presented in Figure 3 and the sampling sites described in Table 1.

Water Quality Analysis

Physicochemical constituents. Water temperature in the Big Sandy Creek ranged from 6°C in January to 26°C in July and August (Figure 4). While water temperature did not vary significantly among the sampling stations within Big Sandy Creek (BS-1, BS-2, BS-3, BS-5), water temperature at the tributary station (BS-4) was generally lower during the summer months and higher during the winter months than water temperatures in Big Sandy Creek itself.

Dissolved oxygen (DO) concentrations and percent oxygen saturations appear to be within the normal range for streams in a climate typical of southeastern Texas. DO concentrations tend to be highest during the winter months when water temperatures are lowest and lowest during the

Table 1. Locations of sampling sites within the Big Sandy Creek Unit with descriptions of stream bottom substrate (from Harrel and Newberry, 1981).

Site	Location	Substrate
BS-1	Big Sandy Creek on the boundary with Alabama-Coushatta Indian Reservation	Fine to coarse sand and silt with plant detritus along channel edges
BS-2	Big Sandy Creek, 100 m downstream from Highway 1276 bridge in north part of Unit	Same as above
BS-3	Big Sandy Creek 20 m downstream from bridge on dirt road near the Lilly home	Same as above
BS-4	Small tributary of Big Sandy Creek 2.4 km (1.5 mi) east of BS-3, 10 m upstream from bridge crossing the road to the Lilly home	Pebbles or gravel mixed
BS-5	Big Sandy Creek 20 m upstream from Highway 1276 bridge near southeast boundary of Unit	Same as BS-1,2,3

YEAR	1975				1976				1977				1978				1979				1980				1981			
SEASON	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W	S	S	F	W
Field Water Quality	▒				▒				▒												▨				▨			
Lab Determined Water Quality	▒				▒				▒												▨				▨			
Dissolved Oxygen	▒				▒				▒												▨				▨			
Turbidity	▒				▒				▒												▨				▨			
Nutrients	▒				▒				▒												▨				▨			
Bacteriological					▒				▒												▨				▨			
Macroinvertebrates																					▒				▒			
Fish Survey									▨				▨															

Big Sandy Creek Unit
Legend:
▨ Monthly Samples
▒ Occasional Samples
Field Water Quality Parameters
Temperature pH
Conductance Color
Nutrients
NO_3-N PO_4-P
NH_4-N
Bacteriological
Fecal Colifarm
Fecal Streptococcis
Macrabenthic Invertebrates
Diversity Index
Fish Survey
Species Identification/Quantification
Lab Determined Parameters
Biochemical Oxygen Demand
Alkalinity, Chloride
TDS, TSS
Total Iron, Chloraphyll "a"

Pertinent Studies: Harrel, 1976
Harrel, 1977
Horrel ond Darville, 1978
Suttkus ond Clemmer, 1979
Horrel and Newberry, 1981

Figure 3. Sampling periods and parameters measured in the Big Sandy Creek Unit.

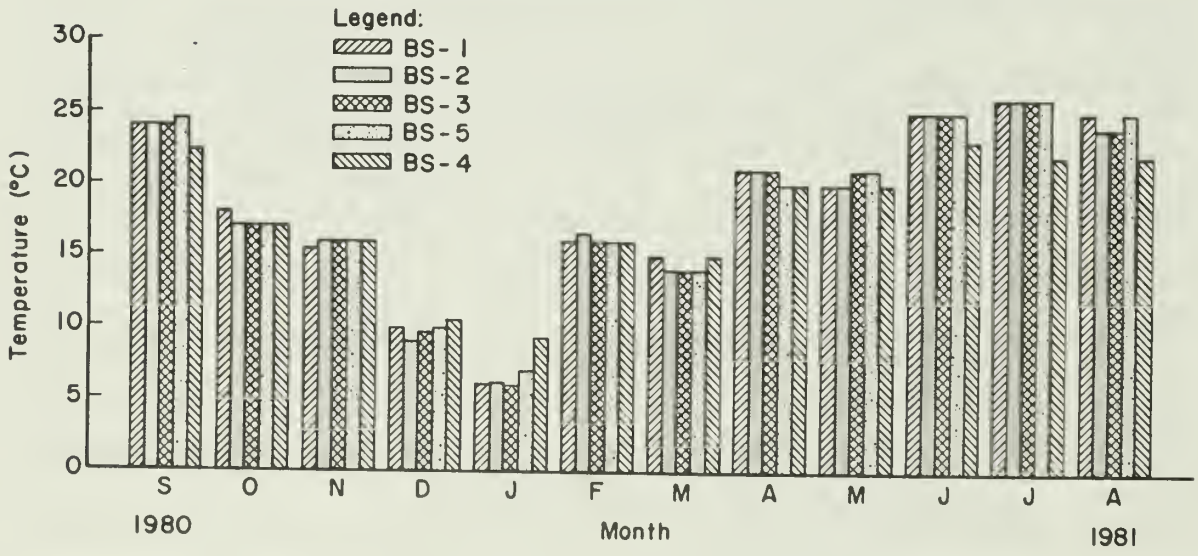

Figure 4. Seasonal profile of water temperatures (1980-1981) for the five sampling sites in the Big Sandy Creek Unit. Data taken from Harrel and Newberry (1981).

summer months when water temperatures are highest. The percent saturation also follows this trend (Figure 5). The majority of samples never fell below the dissolved oxygen criterion of 5.0 mg/l, set by the Texas Surface Water Quality Standards (Texas Department of Water Resources, 1981). Biochemical oxygen demand (BOD) levels in all sites were below 4.1 mg/l, indicating no unusual organic pollutants.

The pH values at each of the four sampling sites within Big Sandy Creek were similar (Figure 6) and yielded a median of 6.1. However, a lower pH was noted in the tributary site (BS-4) where the median value was 5.5. Alkalinity concentrations were low, ranging from 3 - 30 mg/l (as $CaCO_3$), with the lowest alkalinity concentrations (less than 5 mg/l) usually recorded at the tributary site (Figure 7).

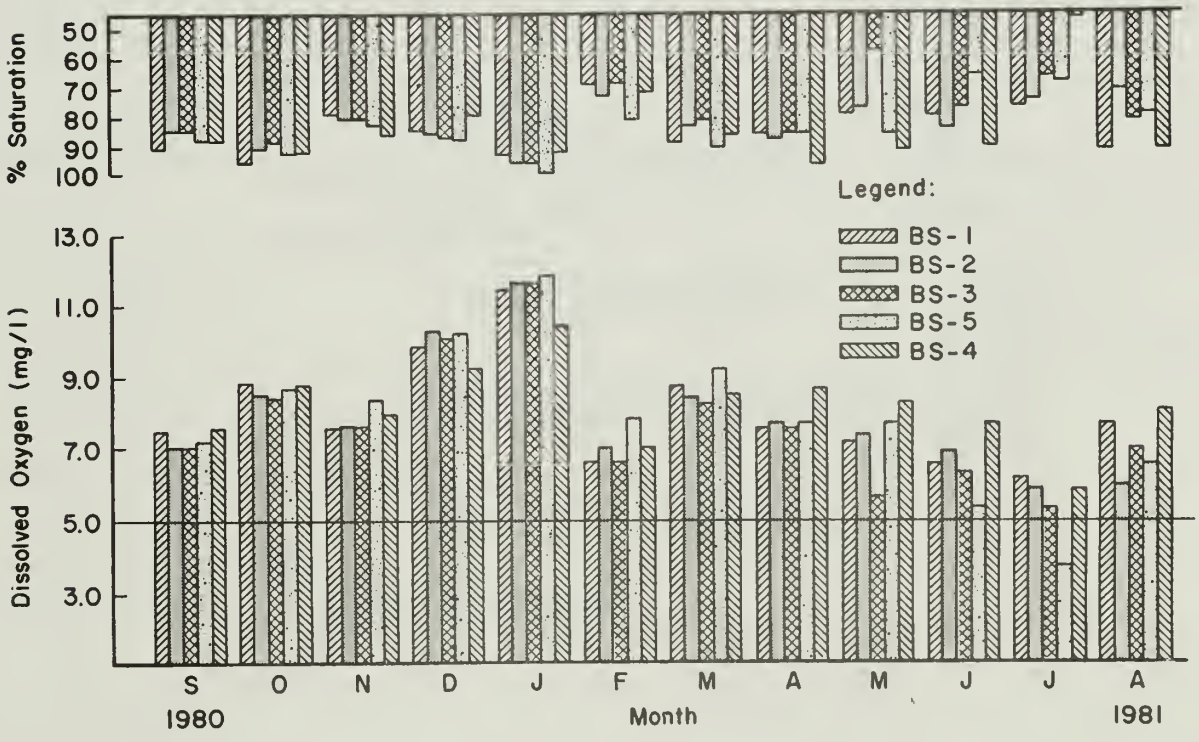

Figure 5. Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1980-1981) for the five sampling sites in the Big Sandy Creek Unit. Data taken from Harrel and Newberry (1981).

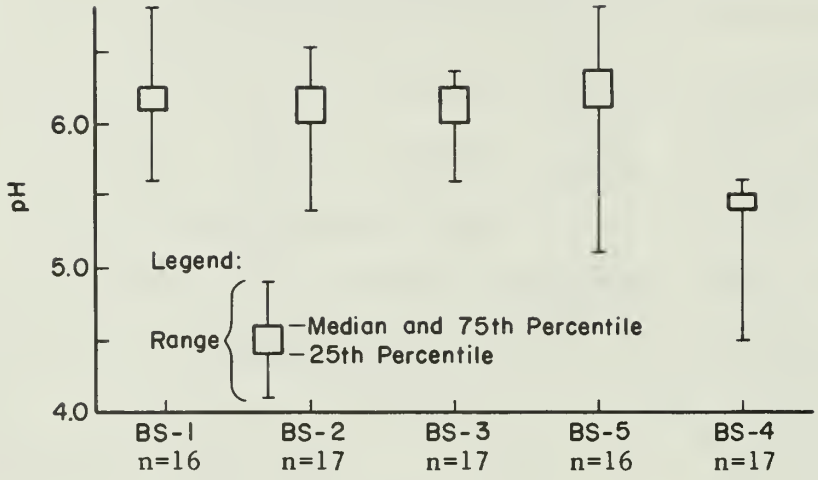

Figure 6. Median and range of pH levels for sampling sites in the Big Sandy Creek Unit (1975-1981). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Newberry (1981).

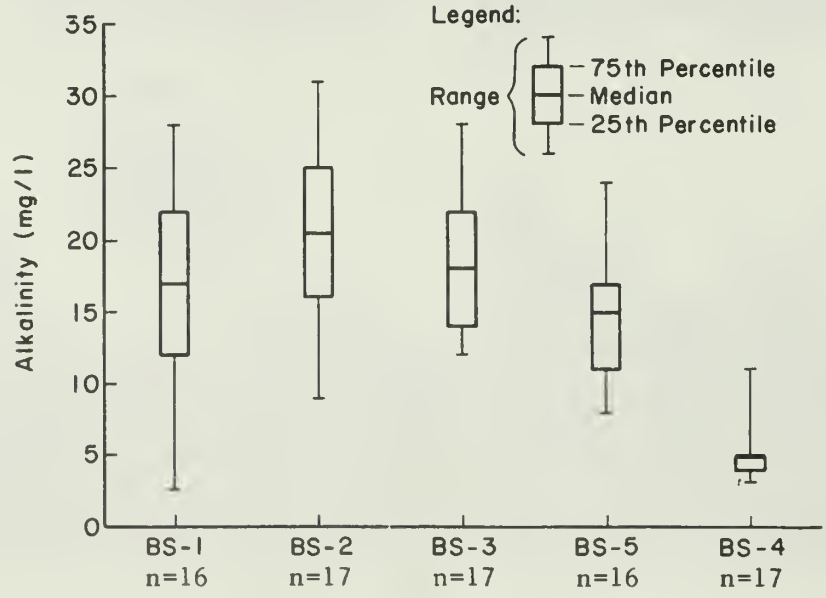

Figure 7. Median and range of alkalinity concentrations for sampling sites in the Big Sandy Creek Unit (1975-1981). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Newberry (1981).

Turbidity levels at the Big Sandy Creek sites were similar, with median values ranging from 32 to 55 during low flows and 49 to 85 during high flows. Turbidity levels tended to be higher at high and intermediate flows (Figure 8). The tributary site appears to have a turbidity level consistently lower than those from the main stem sites.

Specific conductance levels were similar at all Big Sandy Creek sites (Figure 9) with median levels ranging from 76 to 115 µmhos/cm. The measurement of 400 µmhos/cm at site BS-5 probably is an aberration. No downstream trends are apparent in Big Sandy Creek. The specific conductance at the tributary site was lower (median = 35 µmhos/cm) and displayed a smaller range of values than those found at the Big Sandy Creek sites.

Chloride concentrations were low for all sites (Figure 10), with median values ranging from 15 to 19 mg/l. The tributary site had the

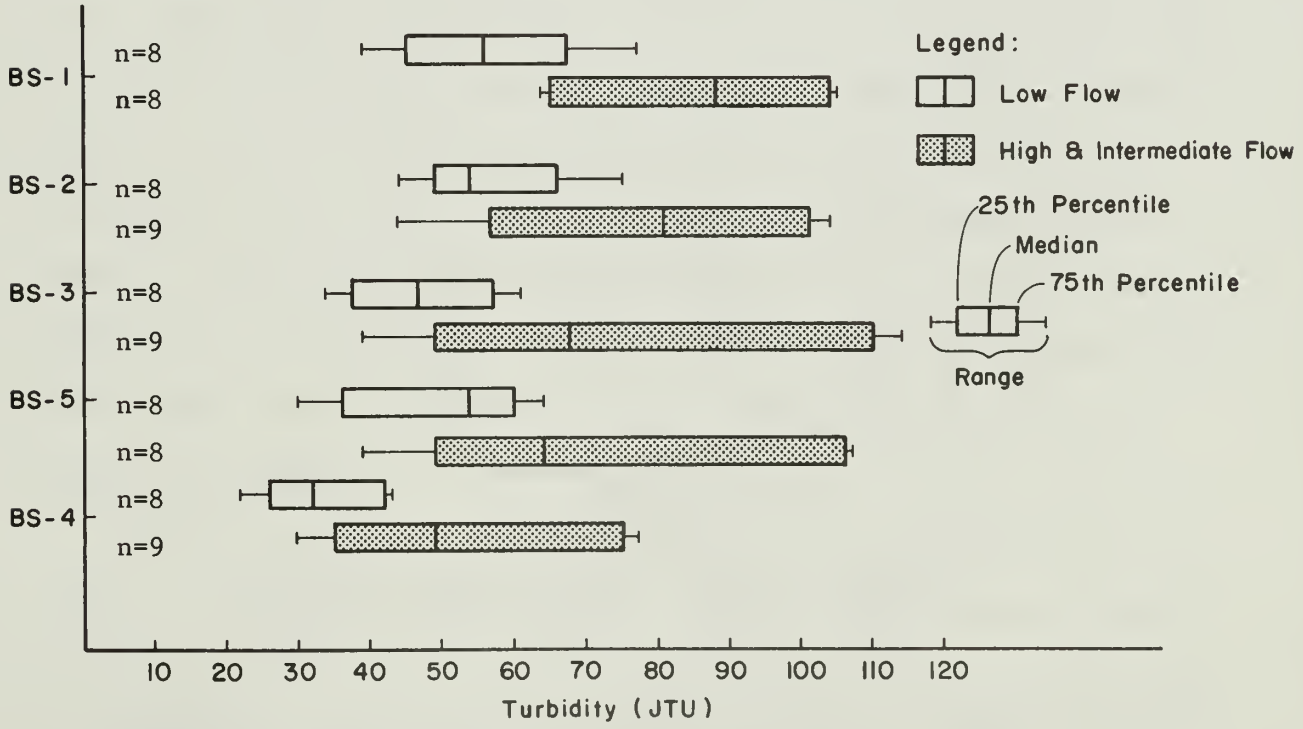

Figure 8. Low flow/high flow turbidity ranges for five sampling sites in the Big Sandy Creek Unit (1975-1981). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Newberry (1981).

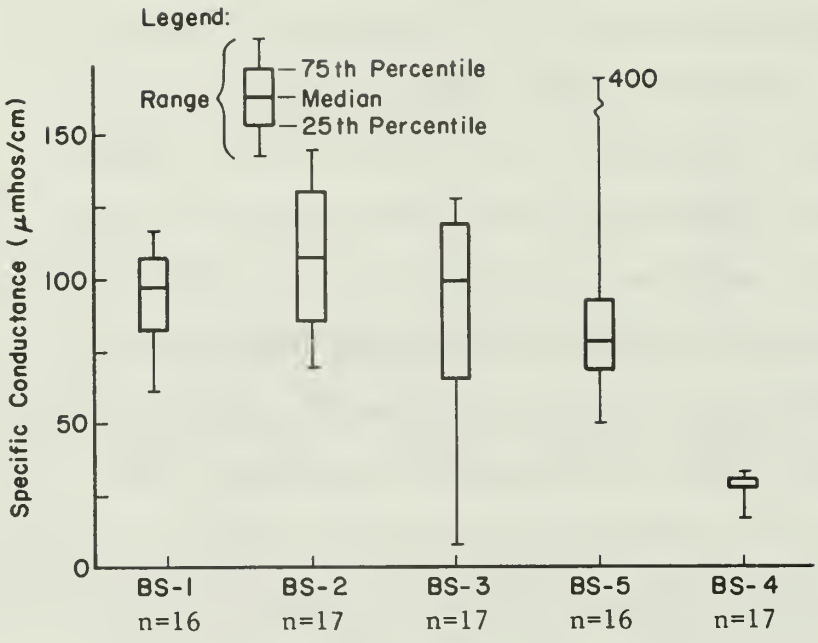

Figure 9. Median and range of specific conductance values for sampling sites in the Big Sandy Creek Unit (1975-1981). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Newberry (1981).

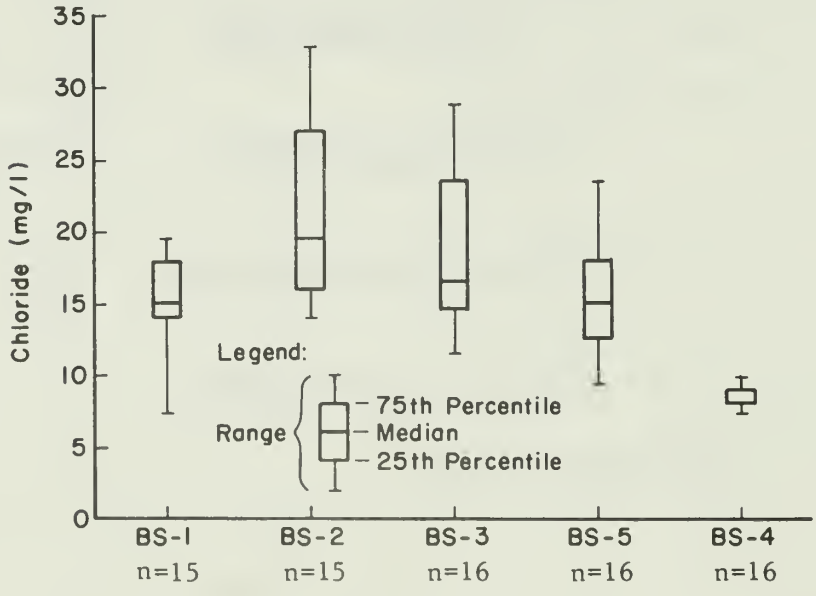

Figure 10. Median and range of chloride concentrations for sampling sites in the Big Sandy Creek Unit (1975-1981). Data taken from Harrel (1977), Harrel and Darville (1978), and Harrel and Newberry (1981).

lowest chloride concentrations of all the sites. There appears to be a slight downstream decrease in chloride concentrations in the four main stem sites.

Concentrations of total dissolved solids (TDS) and total suspended solids (TSS) were low for all sampling sites. Total dissolved solids were less than 60 mg/l, and about 80 percent of TSS were less than 10 mg/l. The tributary site had the lowest TDS and TSS concentrations.

Nutrient chemistry. Nitrate-nitrogen concentrations at all sampling sites were low. Approximately 50 percent of all samples were near or below the detection limit of 0.003 mg/l and well below the federal water quality criteria of 10 mg/l. No seasonal or downstream trends were observed.

Orthophosphate (PO_4) and ammonium-nitrogen concentrations appear to increase at all sampling sites as streamflow increases. Also, a general trend toward higher concentrations of both nutrients occurs during the wet months of April, May, and June (Figure 11). Orthophosphate concentrations appear to behave similarly between the Big Sandy inflow (BS-1) and outflow (BS-5) sites and in both cases were higher than generally found in undisturbed waters of southeastern Texas. No significant downstream trends within the unit were observed for orthophosphate and ammonium-nitrogen concentrations.

Biological Sampling

Bacterial contamination at all sampling sites ranged from slight to moderate (Figure 12). The majority of fecal coliform bacteria levels at all sites were below the Texas State Water Quality Standard of 200 colonies/100 ml for contact recreation. Occasional samples at BS-1, BS-2, and BS-3, however, exceeded this standard.

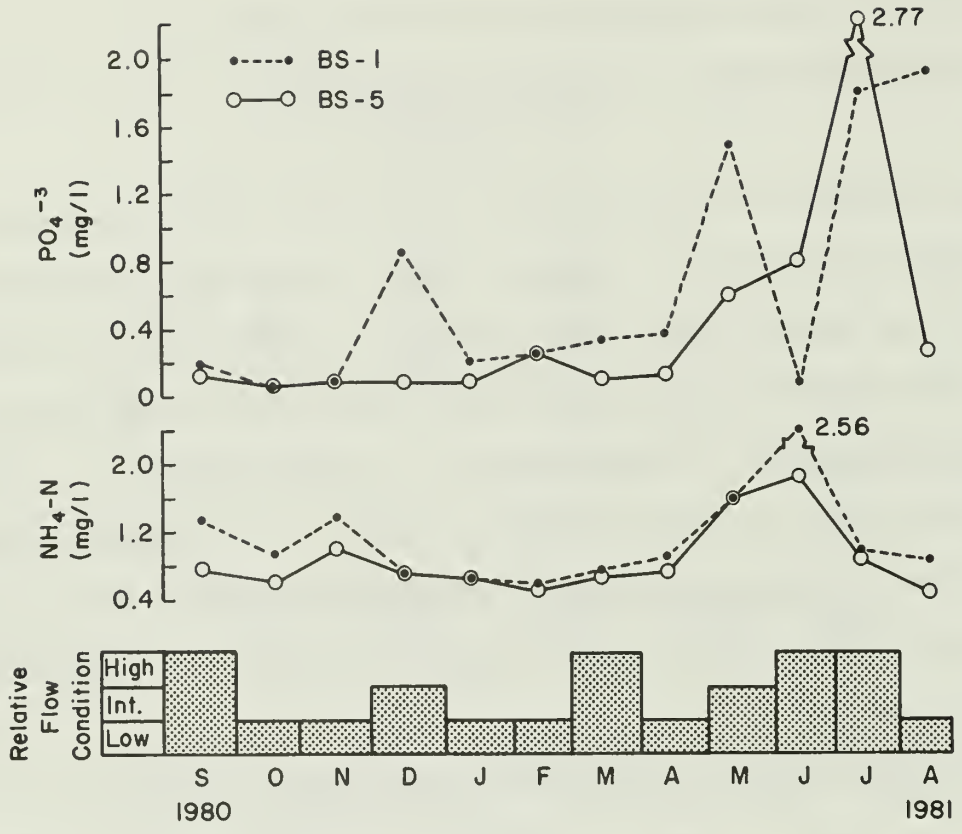

Figure 11. The seasonal relationship of PO_4^{-3} and NH_4^{+}-N with flow regime for two sampling sites representing inputs (BS-1) and outputs (BS-5) to the Big Sandy Creek Unit (1980-1981). Data taken from Harrel and Newberry (1981).

Fecal streptococcus levels were generally higher than those of fecal coliform. Fecal coliform to fecal streptococcus ratios typically were less than 0.7, indicating that bacteria in the streams may be attributable to wildlife or domestic animal populations rather than to human sewage.

Harrel and Newberry (1981) collected and identified more than 171 taxa of macroinvertebrates in Big Sandy Creek. Of these, the most numerous were reported to be the true flies of the Chironomidae family, with the greatest abundance found in the genus Tanytursus. Numerical

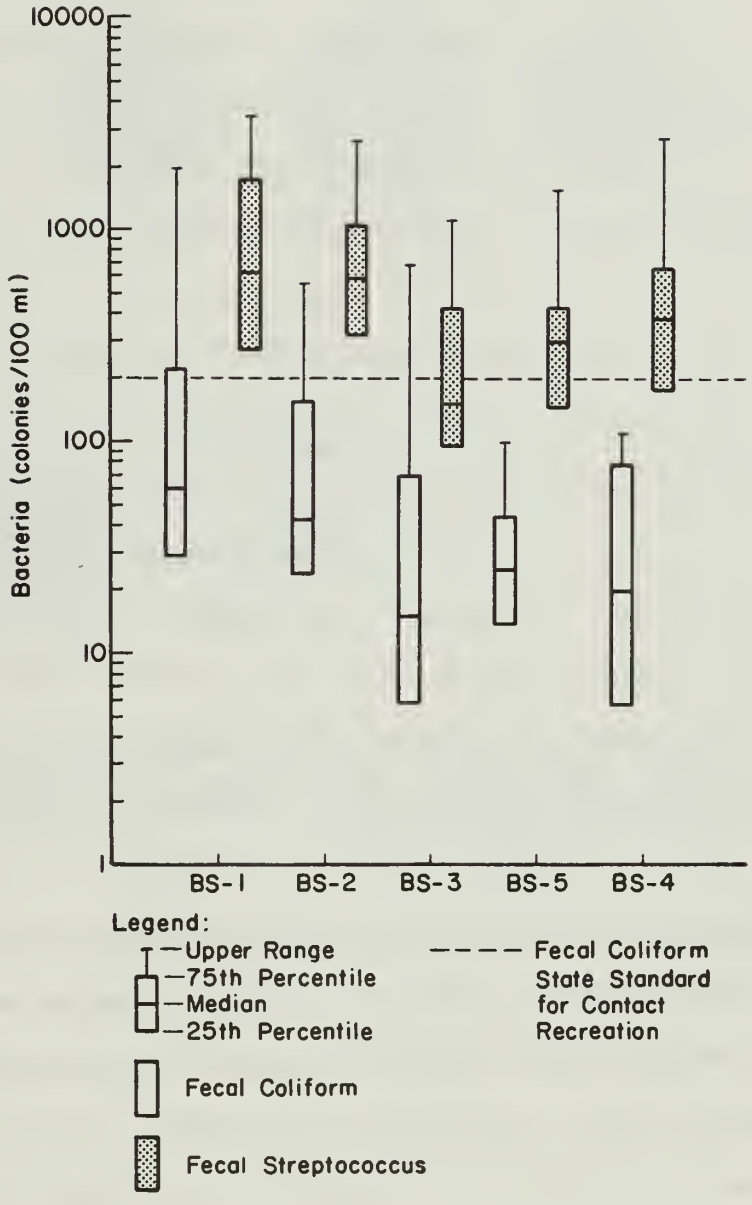

Figure 12. A profile of fecal coliform and fecal streptococcus bacteria counts through the Big Sandy Creek Unit (1980-1981). Data taken from Harrel and Newberry (1981).

distribution of the dominant taxa are presented in Figure 13. The Shannon-Weaver diversity index is greater for macroinvertebrates collected in Big Sandy Creek than for any other stream previously studied in Big Thicket National Preserve, which indicates good water quality.

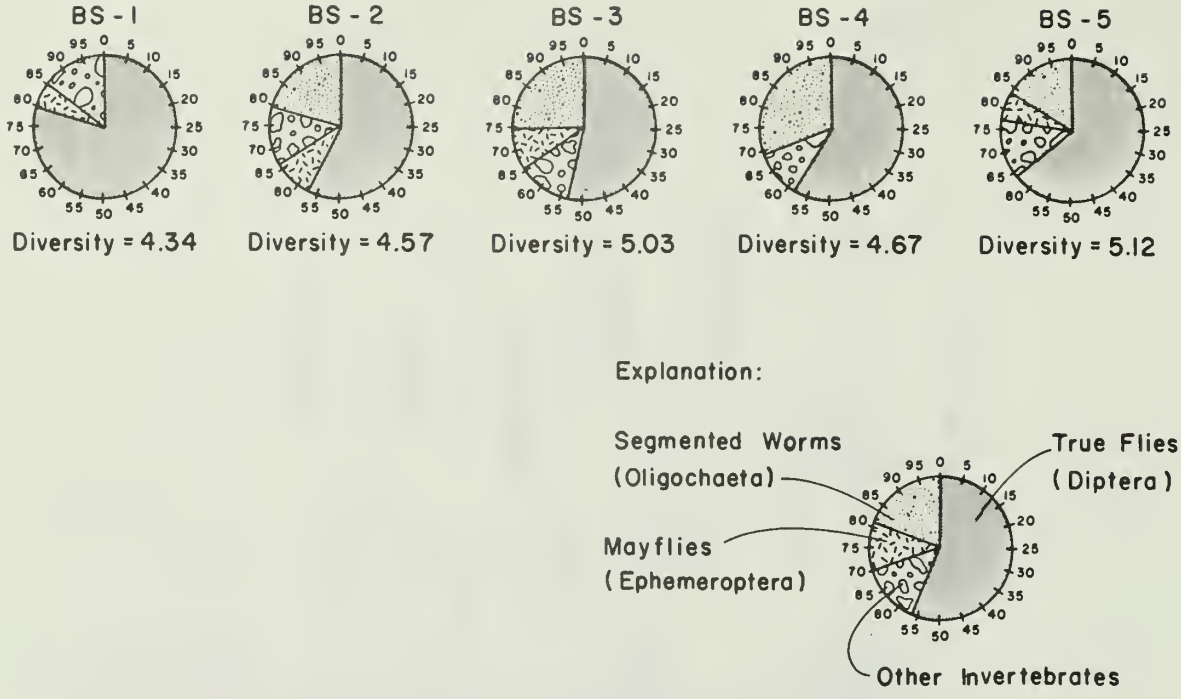

Figure 13. Annual percent distribution of aquatic macroinvertebrates and Shannon-Weaver diversity values for sampling sites of the Big Sandy Creek Unit (1980-1981). Adapted from Harrel and Newberry (1981).

Thirty-nine species of fish were collected in Big Sandy Creek by Suttkus and Clemmer (1979). Ten species each of sunfish and minnows, six species of darters, four species of bullheads, and three species of suckers were collected. In addition, one species each of lamprey, killifish, pike, pirateperch, and silverside were found. Suttkus and Clemmer (1979) also detected seasonal differences in species composition.

Conclusions

The water quality of streams in the Big Sandy Creek Unit appears to be very good. Dissolved oxygen concentrations are high enough to support a diverse and healthy aquatic life and indicate no significant organic pollution of the streams in the unit. The water temperatures

lie within a range capable of supporting warm-water aquatic organisms and would appear to be typical of southeastern Texas. TDS and TSS are low, indicating a low incidence of erosion within the unit. Alkalinity and pH are somewhat lower than might be expected, but the acidic nature of the soils, the presence of organic acids, and the influence of ground water all may contribute to a lower pH and alkalinity.

Specific conductance and chloride concentrations are in the range considered normal for undisturbed watersheds in the southeastern portion of Texas. Turbidity levels are within normal ranges for streams of high color and low-to-moderate suspended solids.

The nutrients orthophosphate and ammonium-nitrogen are not at levels considered detrimental to water quality. However, the concentrations for certain samples seemed high for a stream in an undisturbed area. One explanation could be surface runoff washing the nutrients out of the rapidly decomposing forest litter layer.

The bacterial concentrations found in Big Sandy Creek decreased as the sampling sites became farther from the Alabama-Coushatta Indian Reservation. This may indicate potential contamination of Big Sandy Creek from septic tanks and livestock areas as it flows through the Indian Reservation.

The fish and macroinvertebrate diversity in the Big Sandy Creek Unit indicates a healthy and unstressed aquatic habitat.

As of 1981, there was no evidence that man-caused activities either within or surrounding the Big Sandy Creek Unit were adversely affecting the water quality of streams within the unit.

BEECH CREEK UNIT

General Description

The Beech Creek Management Unit comprises 1,965 ha (4,856 acres) within Tyler County in the upper Big Thicket area. The major stream flowing through the unit is Beech Creek, which originates in eastern Tyler County and flows 52.3 km (32.5 mi) to Village Creek. A 10.3 km (6.4 mi) stretch of Beech Creek lies within the unit. A tributary, Little Beech Creek, flows for 4.0 km (2.5 mi) within the unit. The sections of Beech Creek and Little Beech Creek within the management unit have gradients of 2.05 m/km (10.82 ft/mi) and 1.62 m/km (8.55 ft/mi), respectively (Kost, 1977).

Approximately 92 percent of the soils in the Beech Creek Unit are composed of the Gallime-Alazan and the Mantachie series (Deshotels, 1978). The Gallime-Alazan soils are found on broad mounds and ridges. These soils consist of well-drained, fine sandy loams in the surface horizon and sandy, clayey loams in the subsurface horizons. The water table ranges from 1.219 m (4.0 ft) to 1.83 m (6.0 ft) below the surface at its highest level from December to March. The erosion hazard for Gallime-Alazan soils is slight (Deshotels, 1978). The Mantachie soil series has previously been described in the section on the Big Sandy Creek Unit.

Vegetation in the Beech Creek Unit (Figure 14) is similar to the vegetation found in Big Sandy Creek Unit. Acid bog-baygall associations are found on the floodplains adjacent to Beech and Little Beech Creeks, where topographic slopes within the floodplains are less than 1 percent. Hardwoods of the beech-magnolia-loblolly pine association are found on

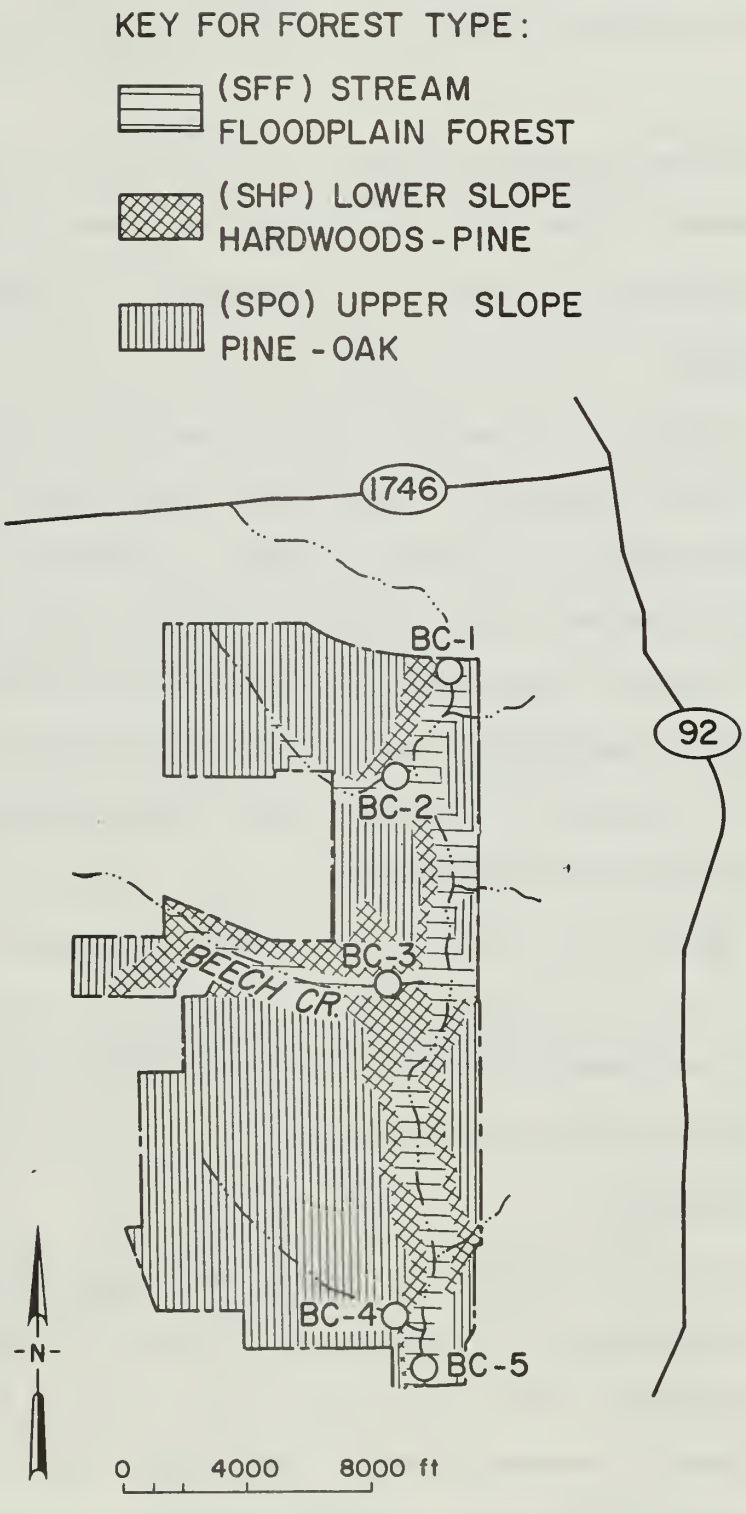

Figure 14. Vegetation map of the Beech Creek Unit with historic sampling sites. Adapted from USDI (1976).

the more gentle upland slopes (1 to 3 percent), while pine-oak associations are found on the steeper upland slopes (>3 percent) of the unit.

Pine has been harvested in the unit in order to salvage timber decimated during a pine bark beetle outbreak. The area immediately north and northeast of the unit was clearcut in 1976 (Kost, 1977).

Previous Studies

Physicochemical parameters were measured and benthic macroinvertebrates collected in Beech Creek during Harrel's 1975 water quality reconnaissance study (Harrel 1976). In Harrel's 1976 study, physicochemical parameters were measured (Harrel, 1977). Kost (1977) conducted a 12-month field study in 1976-77 which included monitoring physicochemical parameters and benthic macroinvertebrates. During the summer of 1977, Harrel and Darville (1978) monitored physicochemical parameters and bacteria in the Beech Creek Unit. Stations used in these studies are described in Table 2, and parameters sampled are shown in Figure 15.

Suttkus and Clemmer (1979) also sampled Beech Creek in their fish survey of Big Thicket National Preserve.

Water Quality Analysis

Physicochemical constituents. Water temperature (Figure 16) and dissolved oxygen (Figure 17) profiles for stations in the Beech Creek Unit vary seasonally. Water temperatures range from 4°C in January to 27°C in August. However, water temperatures did not differ significantly among the stations and fell within established ranges for streams of the Texas Gulf Coast.

Table 2. Locations of sampling sites within the Beech Creek Unit with descriptions of stream bottom substrate (from Kost, 1977).

Site	Location	Substrate
BC-1	Little Beech Creek 30 m downstream from north boundary below tram road	Fine sand and high percentage of silt; plant detritus
BC-2	Tributary to Little Beech Creek, 50 m downstream from dirt road and 0.48 km (0.3 mi) upstream from confluence with Little Beech Creek	Medium to fine sand with some gravel; plant detritus
BC-3	Beech Creek 40 m upstream from dirt road and 2.7 km (1.8 mi) below Odomville bridge	Medium to fine sand with some gravel; plant detritus
BC-4	Tributary to Beech Creek 30 m downstream from dirt road, 0.55 km upstream from confluence with Beech Creek	Fine sand; plant detritus
BC-5	Beech Creek 50 m upstream from south boundary off Horn's Ferry Road connecting FM 92 and FM 2992	Medium to fine sand; plant detritus

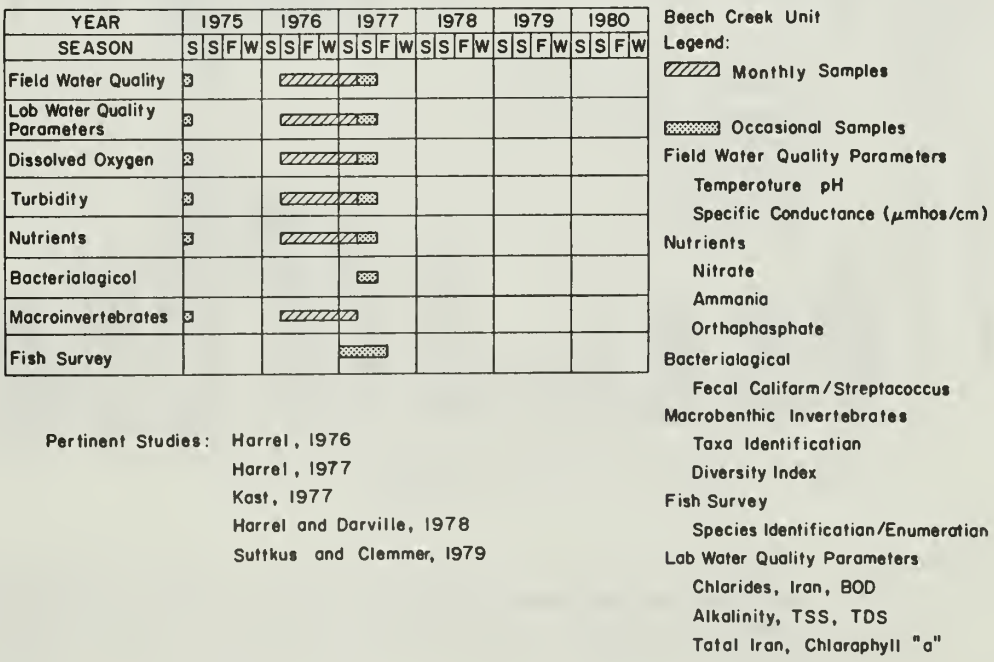

Figure 15. Sampling periods and parameters measured in the Beech Creek Unit.

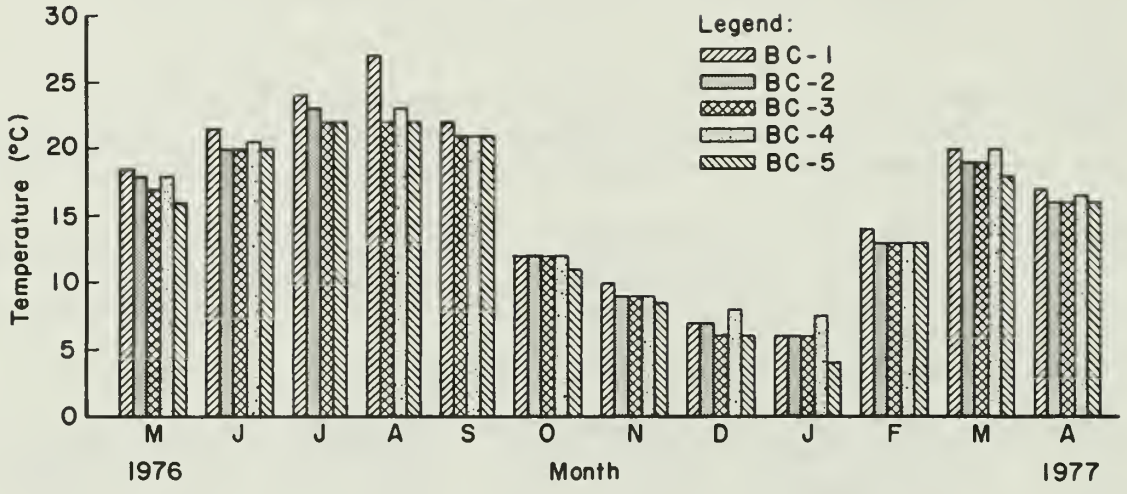

Figure 16. Seasonal profile of water temperatures (1976-1977) for the five sampling sites in the Beech Creek Unit. Data taken from Kost (1977).

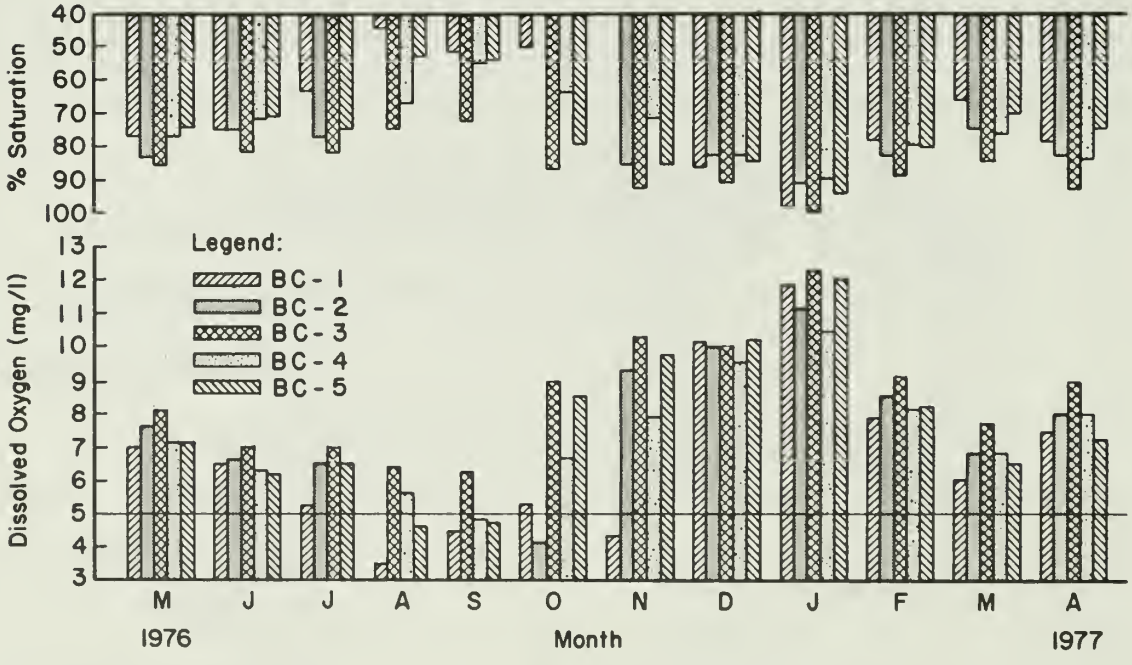

Figure 17. Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1976-1977) for the five sampling sites in the Beech Creek Unit. Data taken from Kost (1977).

Dissolved oxygen concentrations and percent oxygen saturations were generally lower at the Beech Creek sites than those recorded in Big Sandy Creek or Turkey Creek. Lowest dissolved oxygen concentrations and percent saturations occurred during August, September, and October, when several stations in the Beech Creek monitoring network failed to achieve the Texas Surface Water Quality minimum standard of 5.0 mg/l.

The pH of the surface water at the Beech Creek sites was slightly lower than that of Big Sandy Creek with a mean pH of 5.3 (Figure 18). Alkalinity also was lower with a mean of 9.7 mg/l (as $CaCO_3$) (Figure 19). The lower pH and alkalinities do appear, however, to fall within the acceptable range of natural waters in coastal southeastern Texas. The waters are moderately colored ($\bar{X}$ = 176 APHA color units) probably as a result of high concentrations of natural organic acids (Figure 20). These high levels of organic acids in combination with the low buffering capacity of the water may account for the lower pH values in Beech Creek waters.

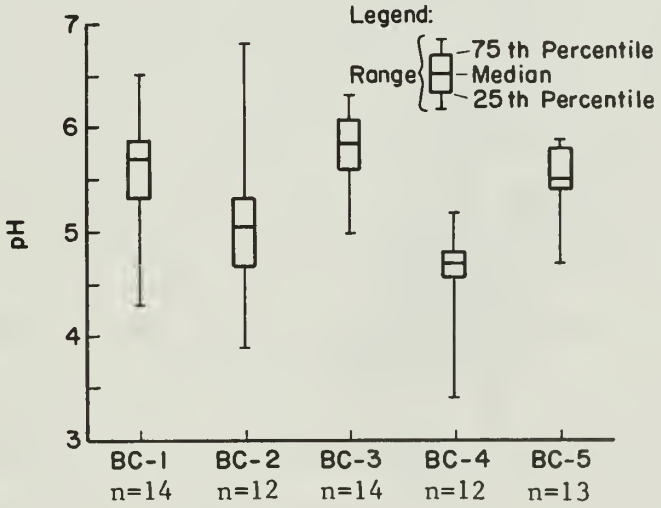

Figure 18. Median and range of pH levels for sampling sites in the Beech Creek Unit (1975-1977). Data taken from Harrel (1976, 1977), Kost (1977), and Harrel and Darville (1978).

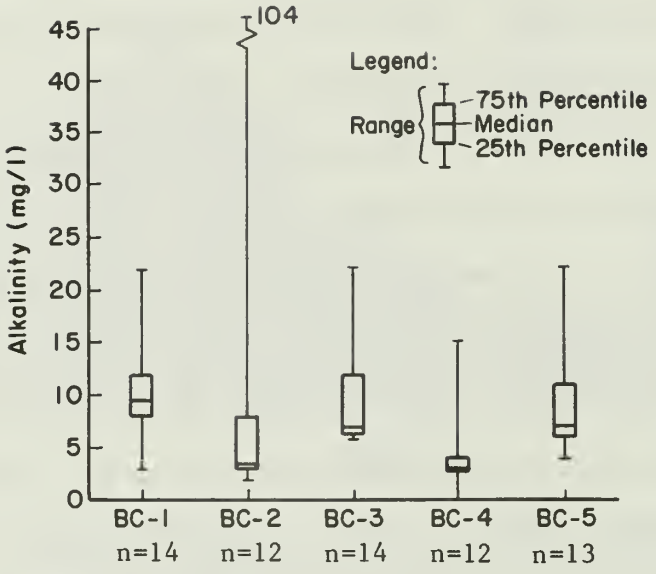

Figure 19. Median and range of alkalinity concentrations for sampling sites in the Beech Creek Unit (1975-1977). Data taken from Harrel (1976, 1977), Kost (1977), and Harrel and Darville (1978).

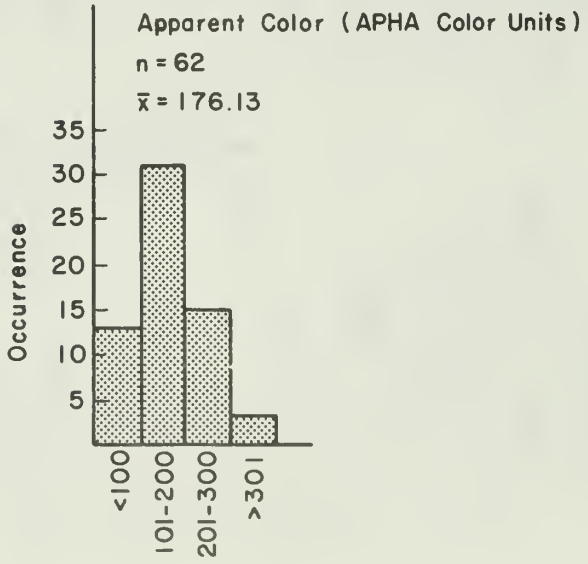

Figure 20. Frequency of occurrence of color values for samples from the Beech Creek Unit (1975-1977). Data taken from Harrel (1976, 1977), Kost (1977), and Harrel and Darville (1978).

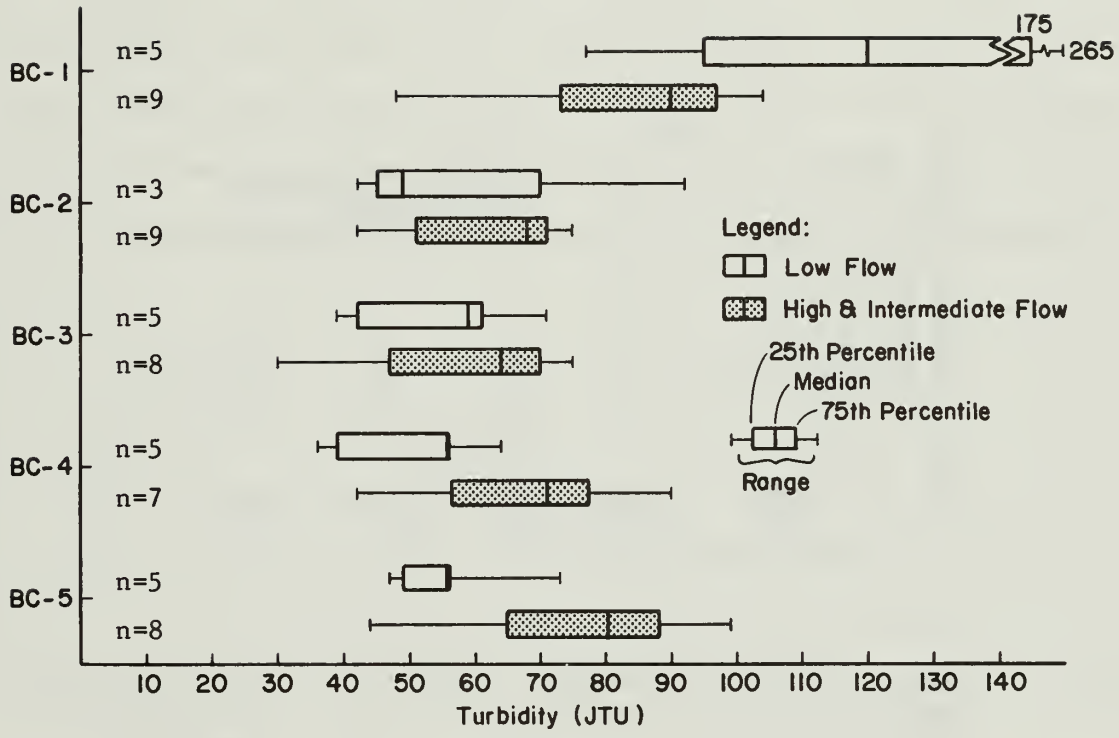

Figure 21. Low flow/high flow turbidity ranges for five sampling sites in the Beech Creek Unit (1975-1977). Data taken from Harrel (1976, 1977), Kost (1977), and Harrel and Darville (1978).

Turbidity levels were generally low to moderate. Median values ranged from 60 to 120 JTU. Tributary sites (BC-2,3,4) tended to have a slightly lower turbidity than the sites on Beech Creek (Figure 21).

Specific conductance and TDS in all samples were low. In 90 percent of all samples, specific conductance was less than 70 µmhos/cm (Figure 22) and TDS was less than 130 mg/l. No seasonal or downstream trends were apparent for either parameter. Chloride concentrations were similar to those found in Big Sandy Creek, with median chloride concentrations occurring between 20 and 25 mg/l (Figure 23).

Nutrient Chemistry. Kost (1977) found that nitrate-nitrogen was usually highest at stations BC-3 or BC-5 and lowest at BC-1 or BC-2.

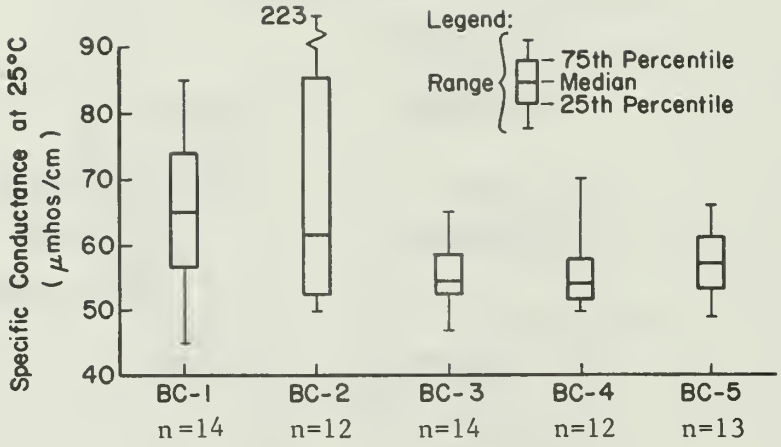

Figure 22. Median and range of specific conductance values for sampling sites in the Beech Creek Unit (1975-1977). Data taken from Harrel (1976, 1977), Kost (1977), and Harrel and Darville (1978).

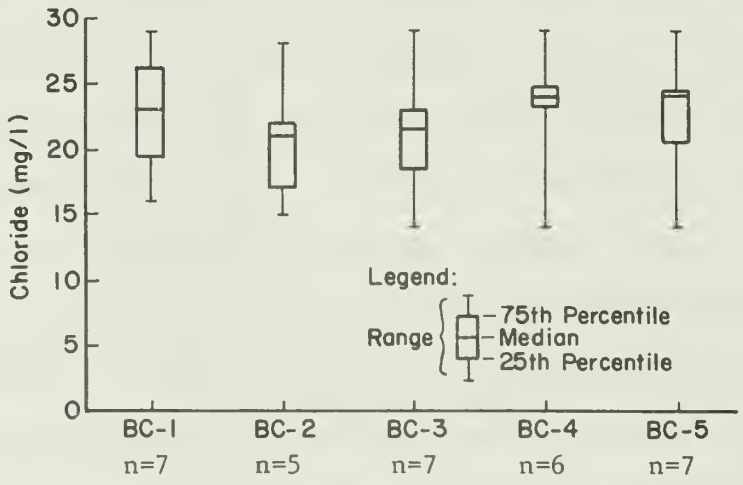

Figure 23. Median and range of chloride concentrations for sampling sites in the Beech Creek Unit (1975-1977). Data taken from Harrel (1976, 1977), Kost (1977), and Harrel and Darville (1978).

Figure 24 illustrates the tendency for nitrate-nitrogen concentrations to be lower at low discharges, especially at BC-5. This relationship may indicate that there is an inflow of nitrogen compounds from the forest floor during periods of high rainfall. By contrast, orthophosphate peaks during periods of low flow, probably because of concentration of biological organisms and a lack of dilution. The orthophosphate

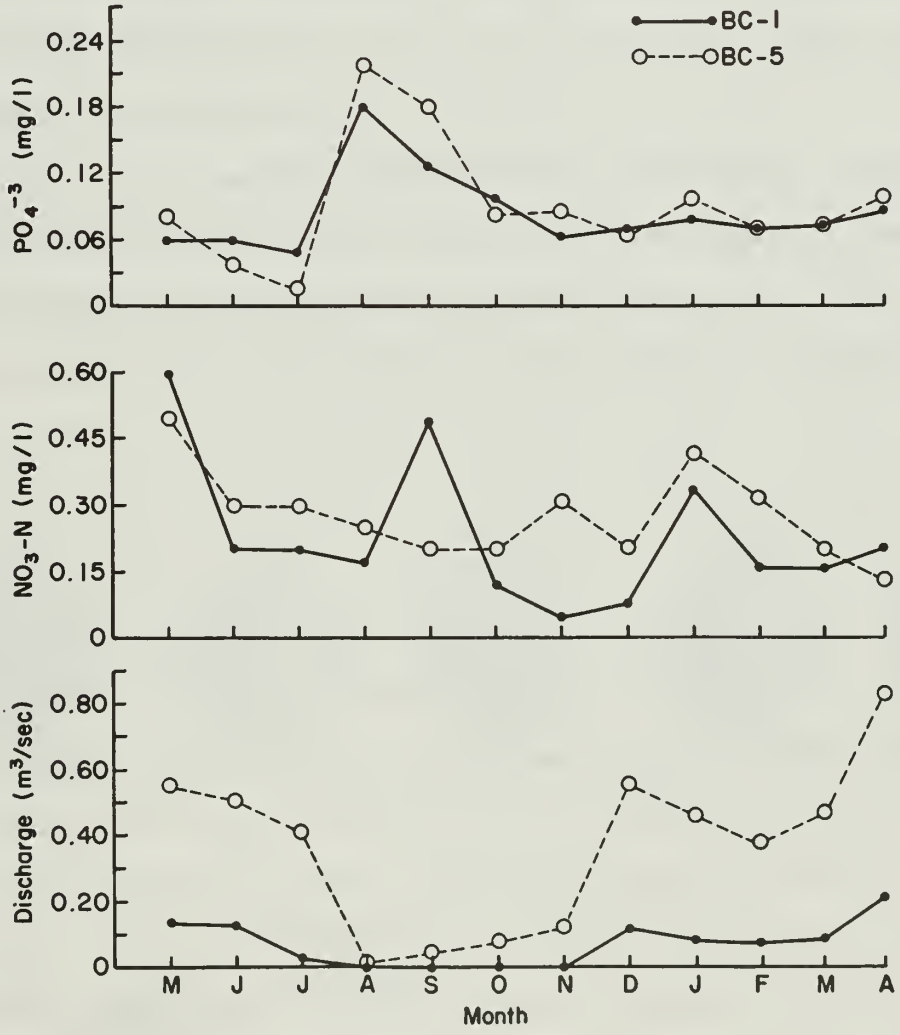

Figure 24. The seasonal relationship of PO_4^{-3} and NO_3-N with discharge for two sampling sites representing inputs (BC-1) and outputs (BC-5) to the Beech Creek Unit (1976-1977). Data taken from Kost (1977).

concentrations determined in Beech Creek by Kost (1977) were significantly lower than those reported by Harrel and Newberry (1981) for Big Sandy Creek and were closer to the range expected for undisturbed waters in southeastern Texas.

Biological Sampling

At the time of this study, limited bacteriological data were available for Beech Creek. One set of samples was reported by Harrel and Darville (1978), but not enough data are available to be conclusive.

Kost (1977) collected 172 taxa of macroinvertebrates during a 12-month study in the Beech Creek watershed. The greatest number of taxa occurred in January at all stations except for BC-2, which peaked in July. The true flies (Diptera) and the segmented worms (Oligochaeta) dominated on an annual basis at all stations (Figure 25). The

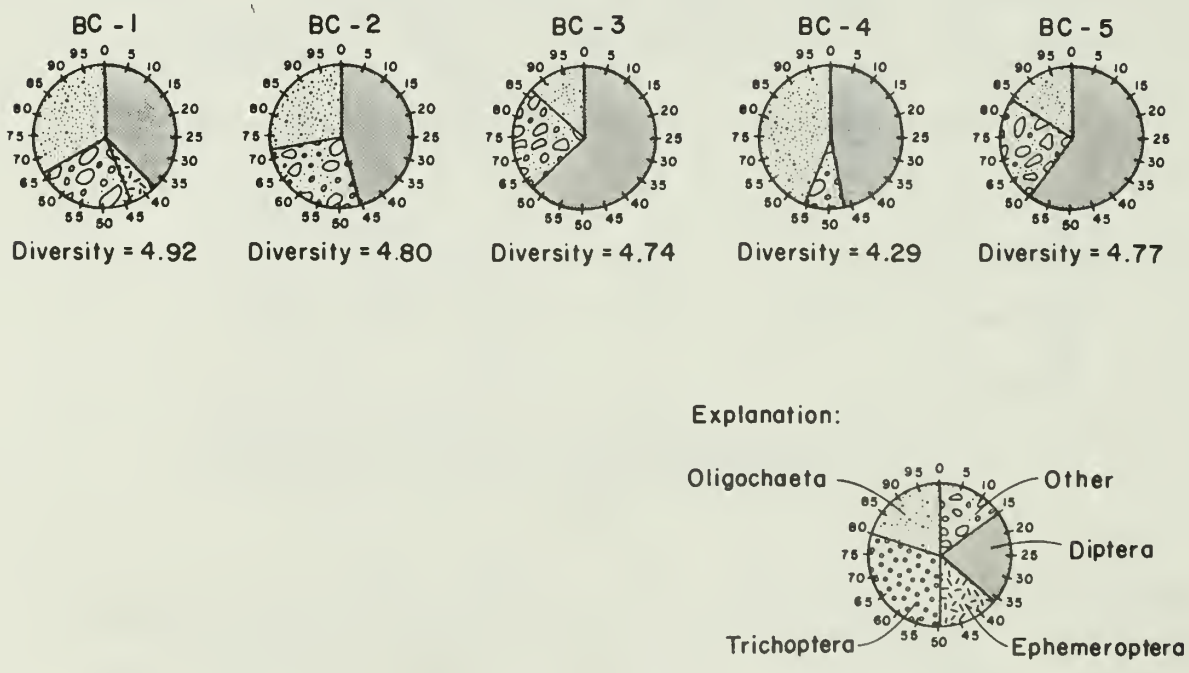

Figure 25. Annual percent distribution of benthic macroinvertebrates and Shannon-Weaver diversity values for sampling locations of the Beech Creek Unit (1976-1977). Data taken from Kost (1977).

chironomid Chladotanytarous was the dominant dipteran. Limnodrilus dominated among the Oligochaeta.

Thirty-eight species of fish were collected in Beech Creek by Suttkus and Clemmer (1979) during various visits to Big Thicket National Preserve. These collections included ten species each of minnow and sunfish, five species of perch, four species of catfish, three species of sucker, and one species each of killifish, live-bearer, lamprey, pike, and silverside.

Conclusions

Summer stream temperatures in the Beech Creek Unit are high but appear to remain below the Texas Surface Water Standard of 32.2°C (90°F) established for neighboring Village Creek . The range of temperatures appears normal for an area with Big Thicket's climate. Summer dissolved oxygen concentrations and oxygen saturations tend to be quite low in Beech Creek and could present a problem in maintaining an adequate diversity of aquatic life. This appears to be a natural situation, as there is no evidence that development in or around the unit is contributing to the low dissolved oxygen concentrations.

Turbidity levels appear to be normal for an area that is influenced by frequent flooding and high water color. The high color values may be due to the leaching of organic acids from decomposing vegetation in the watershed. Kost (1977) found that turbidity, conductivity, and total dissolved solids were low in 1976 despite lumbering activities within and outside the unit. Specific conductance values in Beech Creek are similar to those found in Big Sandy Creek but lower than those found in Turkey Creek. The low pH is likely due to organic acid leaching from the forest floor, and decomposition of wood and other plant material

left within and outside the stream channel during the lumbering operations may also be contributing to the acidic condition (Kost, 1977).

Kost (1977) reported that the community structure of macroinvertebrates characterized by large numbers of taxa indicated that the lumbering activities had no marked effect on community structure. Both benthic macroinvertebrate and fish communities were typical of those found in warm, sluggish streams with sand/silt bottom substrates.

TURKEY CREEK UNIT

General Description

The Turkey Creek Management Unit (Figure 26) comprises 3153 ha (7790 acres) in southern Tyler and northern Hardin counties. Situated on the Bentley geologic formation just south of the Hockley Scarp, this unit lies within the Lissie sands recharge zone of the Chicot aquifer, which provides rainwater recharge to the Gulf Coast aquifers (Lower Neches Valley Authority, 1976).

Three major streams traverse the Turkey Creek Unit. Turkey Creek runs from north to south for more than 30 km (18 mi) along the entire length of the unit before emptying into Village Creek. The lower portion of Hickory Creek and a small section of Village Creek also cross the extreme southern portion of the Unit. Water quality data are available for each of these three streams.

Harrel and Commander (1980) reported five permitted waste discharges into Turkey Creek upstream of the Turkey Creek Management Unit. All five of the permits are for sewage effluent, and more than 90 percent of the wastewater loading originates in the city of Woodville. The Lower Neches Valley Authority (1978) estimates that the BOD_5 loading in Turkey Creek may increase five-fold by the year 2000.

A considerable amount of development has occurred and is projected to continue within and surrounding the unit. Oil field activities can be found within and on the periphery of the unit. Canoe and hiking trails are established, and additional recreational development is planned.

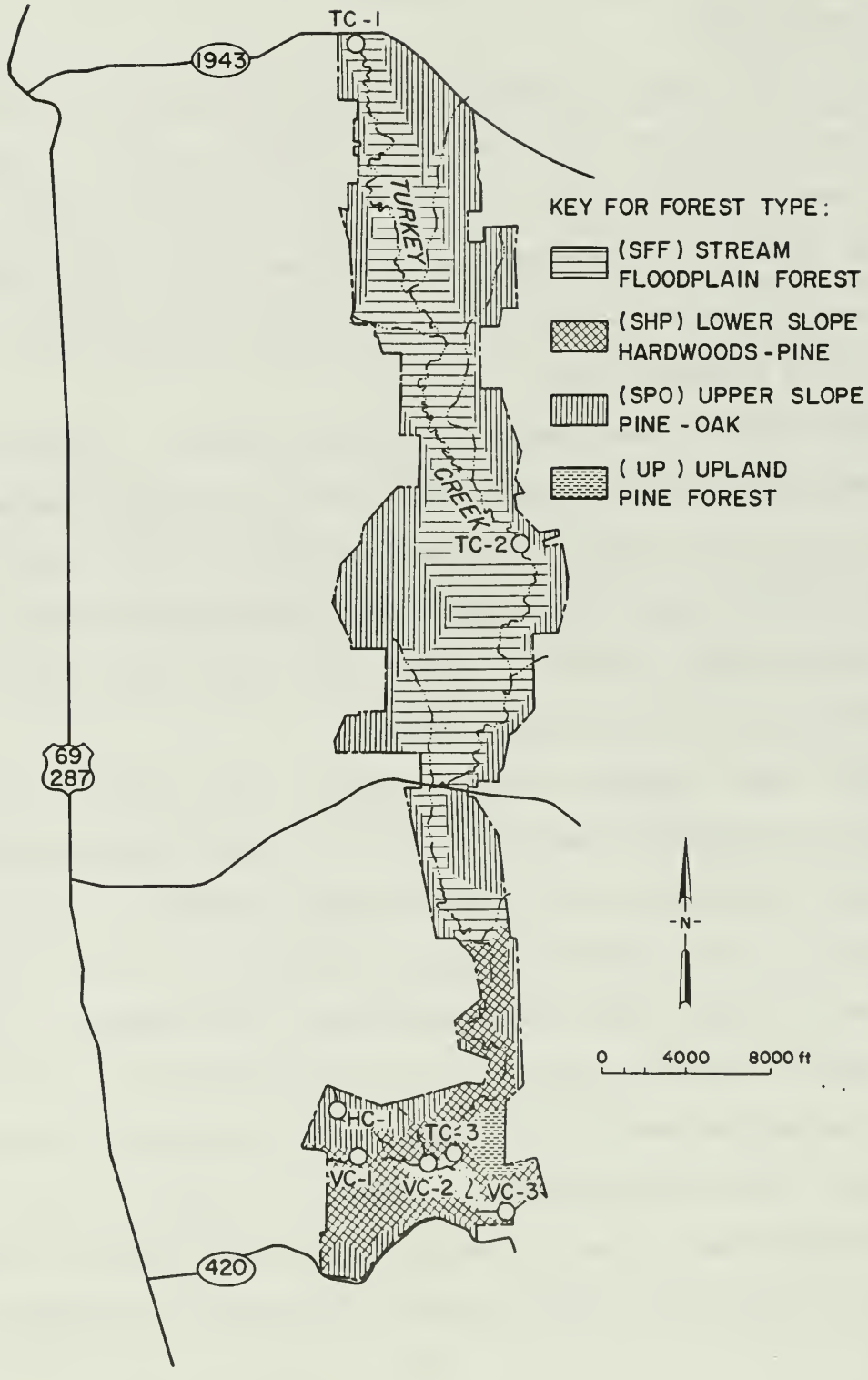

Figure 26. Vegetation map of the Turkey Creek Unit with historic sampling sites. Adapted from USDI (1976).

The Turkey Creek Unit is a mosaic of 14 different soil types. Three of these soil types occupy approximately 60 to 70 percent of the unit and include the Mantachie, Bienville, and Otanya soil series. The Mantachie series are the frequently flooded fine sandy loams described in the Big Sandy Creek Unit section. The Bienville soils are loamy fine sands found on upland sites of 1 to 5 percent slope. These soils are excessively drained with rapid permeability. The Otanya soils are fine sandy loams found on upland areas of 1 to 5 percent slope. These soils are moderately well-drained with a moderately slow permeability. The subsurface contains a layer of impermeable plinthite (Deshotels, 1978).

The variety of soil types within the Turkey Creek Unit contributes to the high diversity of vegetation in the unit. Acid bog-baygall associations dominate on the floodplains adjacent to stream channels. Ridges of sand provide habitat for sandjack oak - black hickory associations. Upland forests of longleaf pine are common, as are savannahs that support an extensive population of carnivorous pitcher plants.

Previous Studies and Applicable State Standards

The reconnaissance studies by Harrel (1976,1977) established four sampling sites on Turkey Creek, one site on Hickory Creek, and three sites on Village Creek. The subsequent study by Harrel and Darville (1978) retained these sampling sites while the study by Harrel and Commander (1980) eliminated one site on Turkey Creek. The sampling sites used by Harrel and Commander are shown in Figure 26 and described in Table 3. Sampling periods and parameters sampled are given in Figure 27.

Table 3. Locations of sampling sites within the Turkey Creek Unit with descriptions of stream bottom substrate (from Harrel and Commander, 1980).

Site	Location	Substrate
VC-1	On Village Creek about 50 m upstream of confluence with Hickory Creek	Coarse sand with sparse pockets of silt and detritus
VC-2	On Village Creek about half the distance between the confluences of Hickory and Turkey Creeks with Village Creek	Coarse sand with sparse pockets of silt and detritus
VC-3	On Village Creek about 30 m downstream from the confluence of Turkey Creek with Village Creek	Coarse sand with sparse pockets of silt and detritus
HC-1	On Hickory Creek about 50 m upstream from the confluence with Village Creek	Coarse sand with sparse pockets of silt and detritus
TC-1	On Turkey Creek about 35 m downstream from FM 1943, east of Warren near north boundary	Coarse sand with sparse pockets of silt and detritus
TC-2	On Turkey Creek at bridge crossing of county road west of Pleasant Valley Church	Coarse sand with sparse pockets of silt and detritus
TC-3	On Turkey Creek about 40 m upstream from the confluence with Village Creek	Coarse sand with sparse pockets of silt and detritus

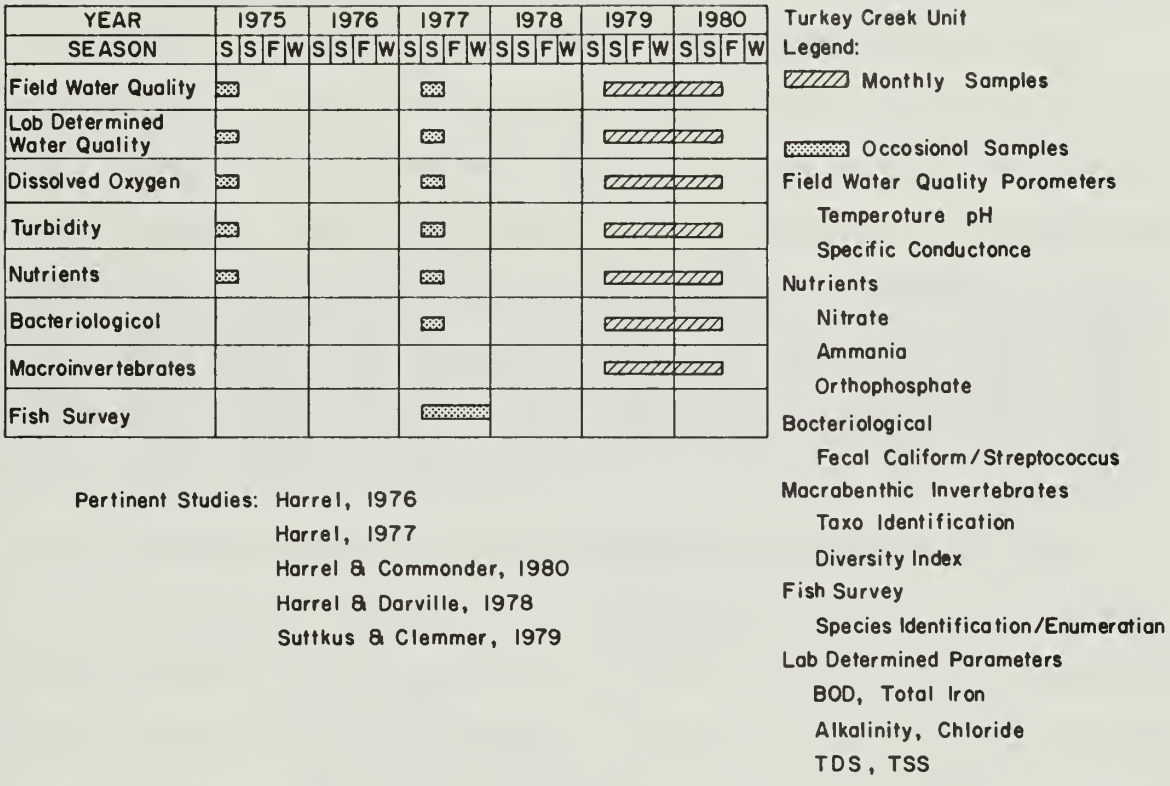

Figure 27. Sampling periods and parameters measured in the Turkey Creek Unit.

Specific stream water quality standards have been developed for Village Creek (Texas Department of Water Resources, 1981). These include:

temperature (max.)	32°C (90°F)
pH range	6.0 - 8.5
dissolved oxygen	not less than 5.0 mg/l
chloride	mean not to exceed 150 mg/l
sulfate	mean not to exceed 75 mg/l
total dissolved solids	mean not to exceed 300 mg/l
fecal coliform	200 organisms/100 ml

These standards apply only to Village Creek and not Turkey Creek or Hickory Creek.

Water Quality Analysis

Physicochemical constituents. Both water temperature (Figure 28) and dissolved oxygen concentrations (Figures 29 and 30) in Turkey Creek, Hickory Creek, and Village Creek display the same seasonal patterns as described for Big Sandy Creek and Beech Creek. While summer stream temperatures tended to be slightly warmer in Turkey Creek than in either Village Creek or Hickory Creek, stream temperatures at all monitoring sites were below the maximum temperature (32.2°C) allowed in Village Creek according to the Texas Surface Water Quality Standards.

Dissolved oxygen concentrations and percent oxygen saturation were highest during the winter months and lowest during the summer months. Although slightly lower in Village Creek than in either Turkey Creek or Hickory Creek, in all cases the DO concentrations exceeded the state minimum standard at all sites. In addition, DO concentrations were similar to those in Big Sandy Creek and significantly higher than those reported previously by Kost (1977) during his study of Beech Creek.

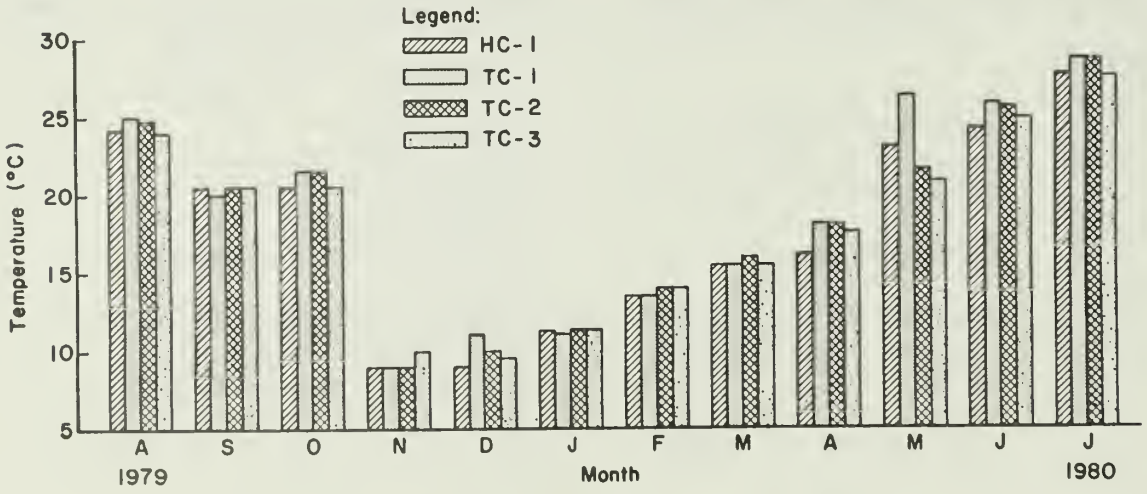

Figure 28. Seasonal profile of water temperature (1979-1980) for the Turkey Creek and Hickory Creek stations in the Turkey Creek Unit. Data taken from Harrel and Commander (1980).

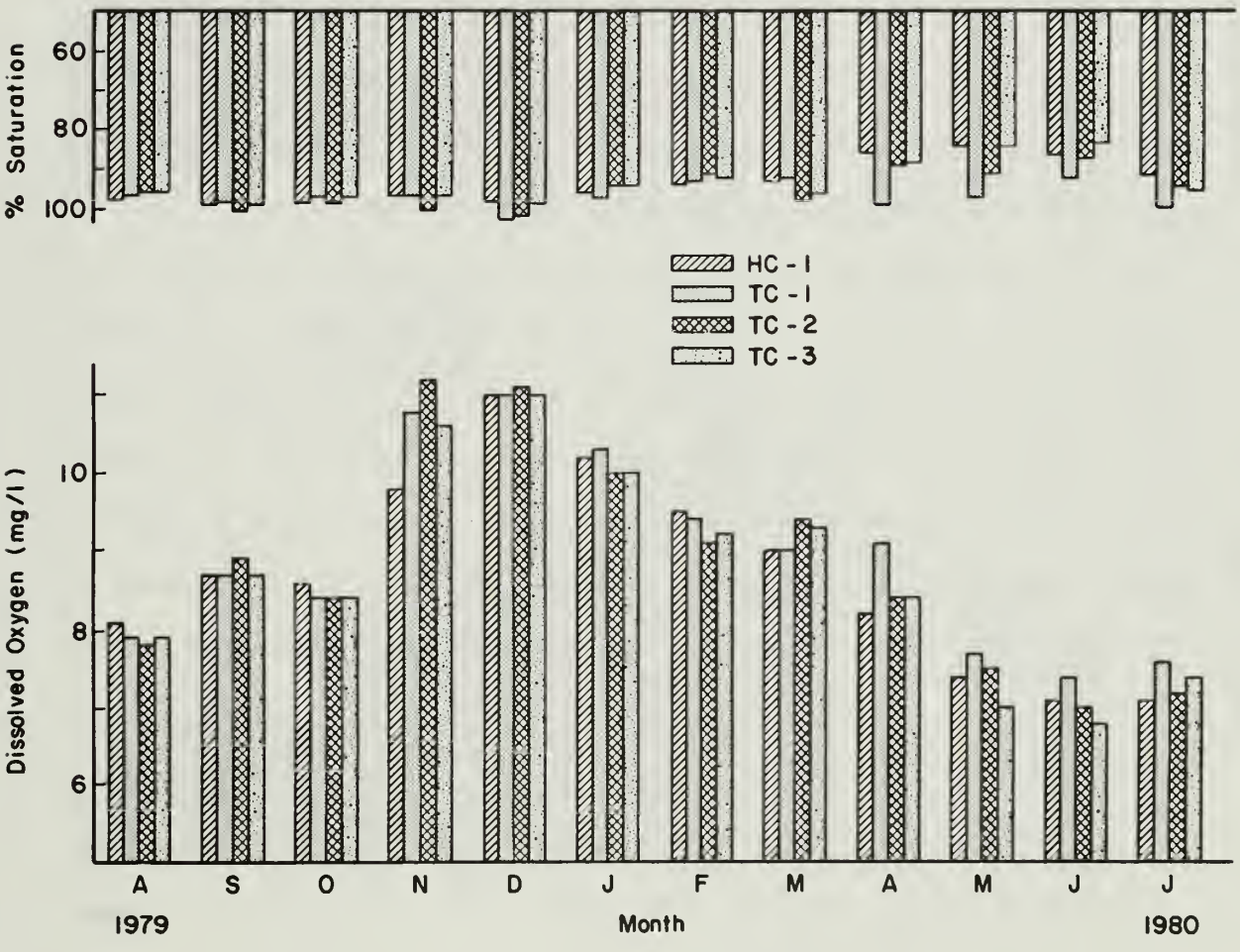

Figure 29. Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1979-1980) for the Turkey Creek and Hickory Creek sampling sites in the Turkey Creek Unit. The Texas state water quality standard for dissolved oxygen is 5 mg/ℓ (minimum) (Texas Dept. of Water Resources, 1981). Data taken from Harrel and Commander (1980).

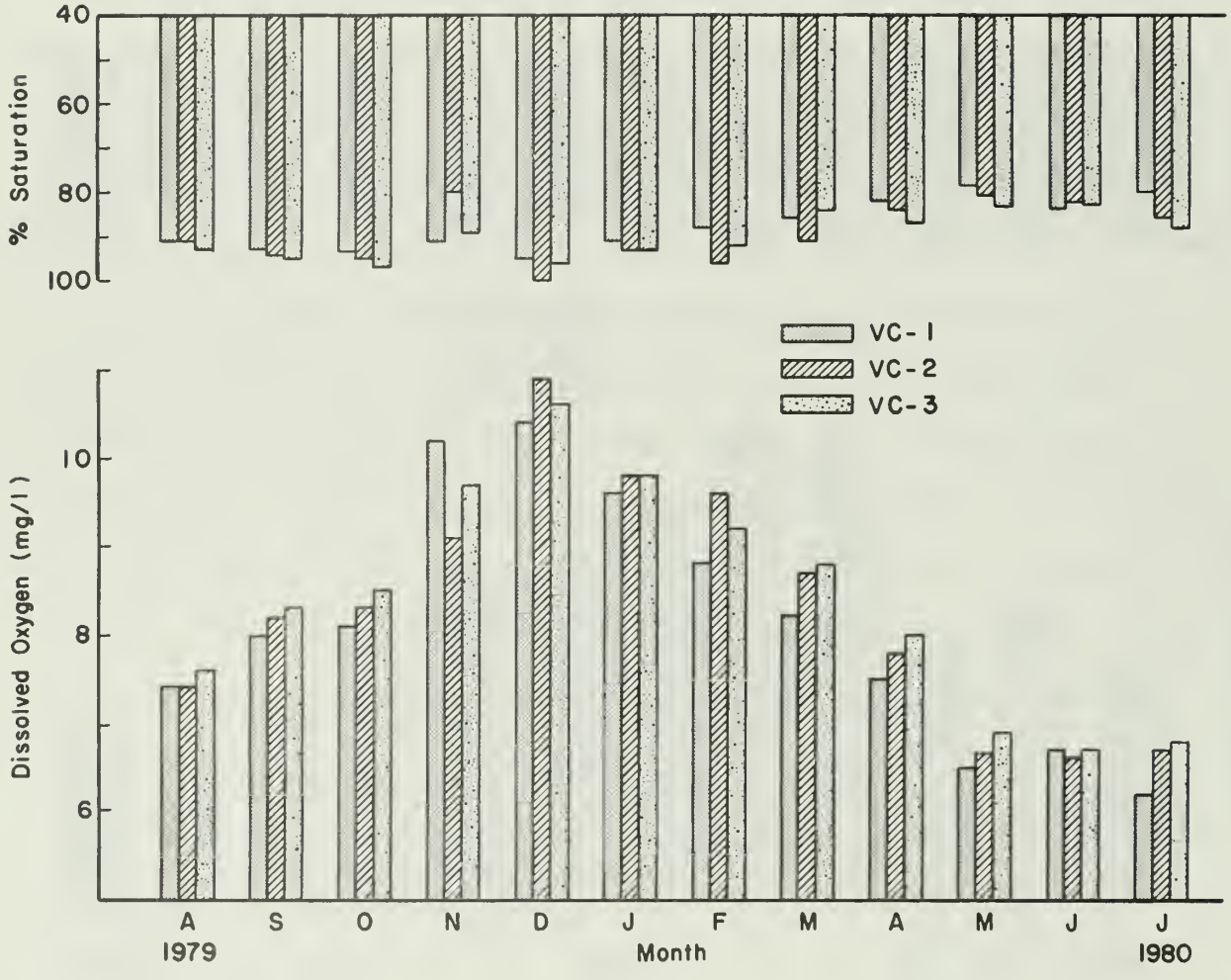

Figure 30. Seasonal profile of dissolved oxygen concentrations and percent oxygen saturations (1979-1980) for the Village Creek sites in the Turkey Creek Unit. The Texas state water quality standard for dissolved oxygen is 5 mg/ℓ (minimum) (Texas Dept. of Water Resources, 1981). Data taken from Harrel and Commander (1980).

The pH values (Figure 31) at all seven sampling sites were similar. Median pH values were between 6.1 and 6.2, with over 50 percent of the pH values falling within the narrow range of 6.0 to 6.3. These data are similar to data reported for the main stem of Big Sandy Creek and slightly higher than the pH values reported for Beech Creek. Alkalinity concentrations are low, as is typical for the surface waters of the Big Thicket. Median alkalinities ranged from 12 to 14 mg/l (as $CaCO_3$) for all seven sampling locations in the Turkey Creek Unit (Figure 32).

Color and turbidity levels in the streams of the Turkey Creek Unit were similar to those found in the streams of the Big Sandy and Beech Creek Units. Ninety percent of all samples in the Turkey Creek Unit had colors ranging from 51 to 200 CU (Figure 33). Median turbidities in the streams of the Unit were in the vicinity of 60 JTU (Figure 34). Turbidities were slightly higher (medians = 70 - 80 JTU) during periods of high flow. In general, turbidity levels were similar in range and pattern to those of Big Sandy and Beech Creeks.

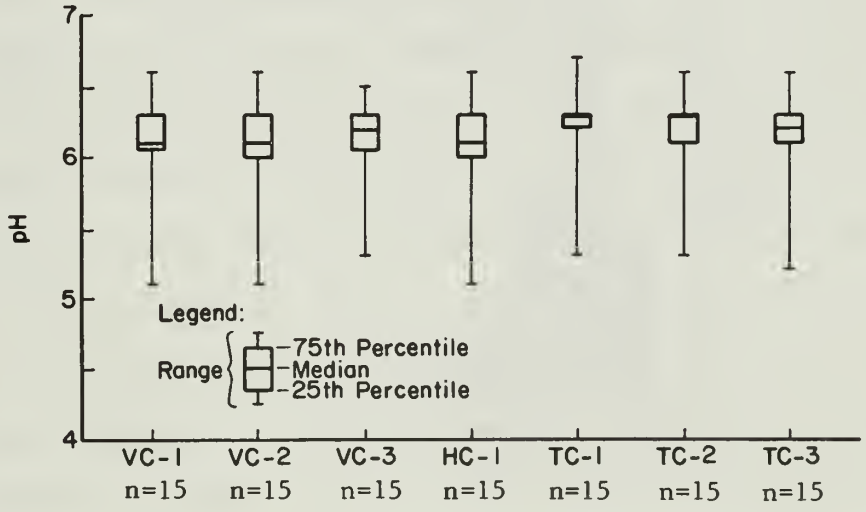

Figure 31. Median and range of pH levels for sampling sites in the Turkey Creek Unit (1975-1980). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Commander (1980).

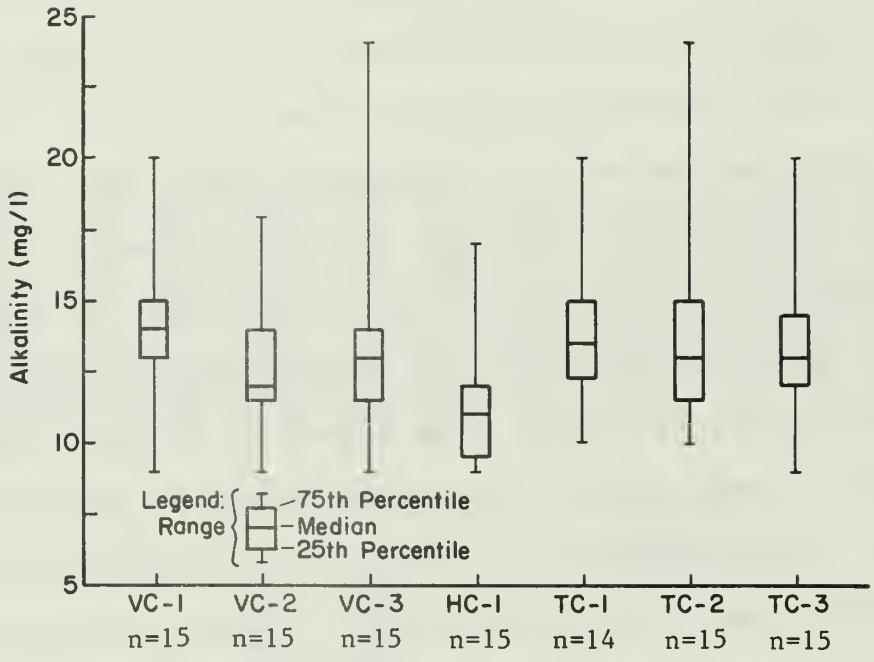

Figure 32. Median and range of alkalinity concentrations for sampling sites in the Turkey Creek Unit (1975-1980). Data taken from harrel (1976, 1977) and Harrel and Commander (1980).

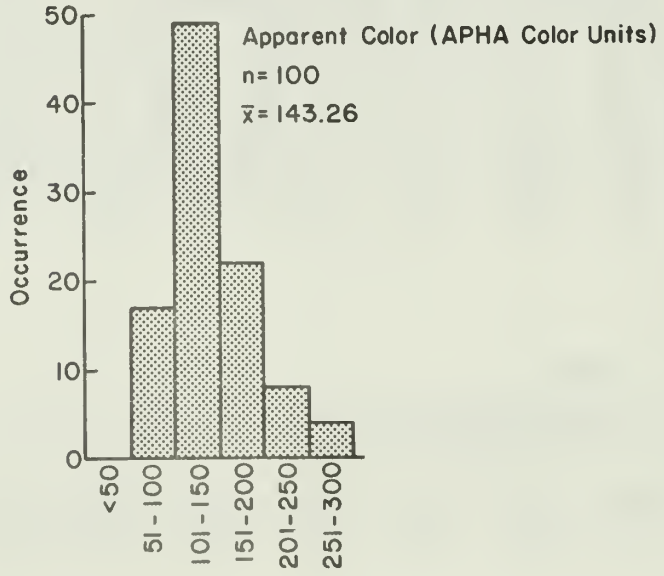

Figure 33. Frequency of occurrence of color values for samples from the Turkey Creek Unit (1975-1980). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Commander (1980).

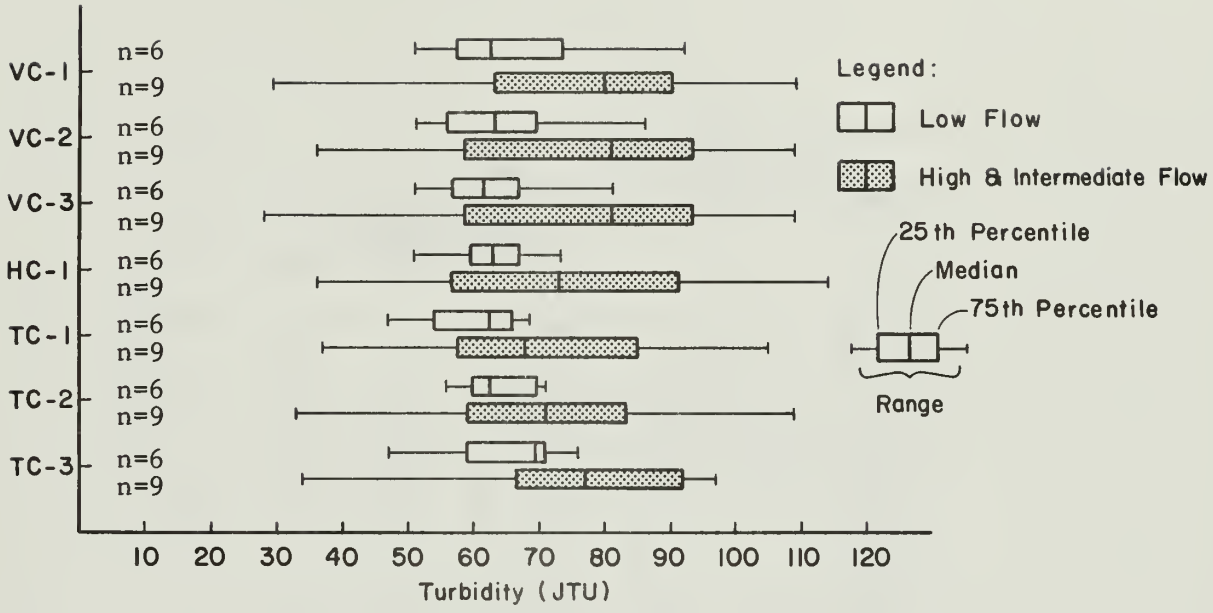

Figure 34. Low flow/high flow turbidity ranges for seven sampling sites in the Turkey Creek Unit (1975-1980). Data taken from Harrel (1976), Harrel and Darville (1978), and Harrel and Commander (1980). Data taken from Harrel (1976, 1977) and Harrel and Commander (1980).

Specific conductance and chloride concentrations in Turkey Creek were generally within the range normally occurring in the streams of southeastern Texas. Occasional sharp increases in both specific conductance (Figure 35) and chlorides (Figure 36), however, were detected in both Village Creek and Hickory Creek. These "spikes" are similar to those seen in Little Pine Island Bayou (Harrel and Darville, 1978) and can probably be attributed to periodic overflow and/or leaching of produced water impoundments that are used for the disposal of saltwater during oil operations in the Village Creek and Hickory Creek watersheds.

Nutrient Chemistry. Data for ammonium-nitrogen and orthophosphate are presented in Figures 37 and 38. Ammonium concentrations were generally higher in Village Creek (where median concentrations ranged from 1.0 - 1.3 mg/l) than in Turkey Creek or Hickory Creek, where

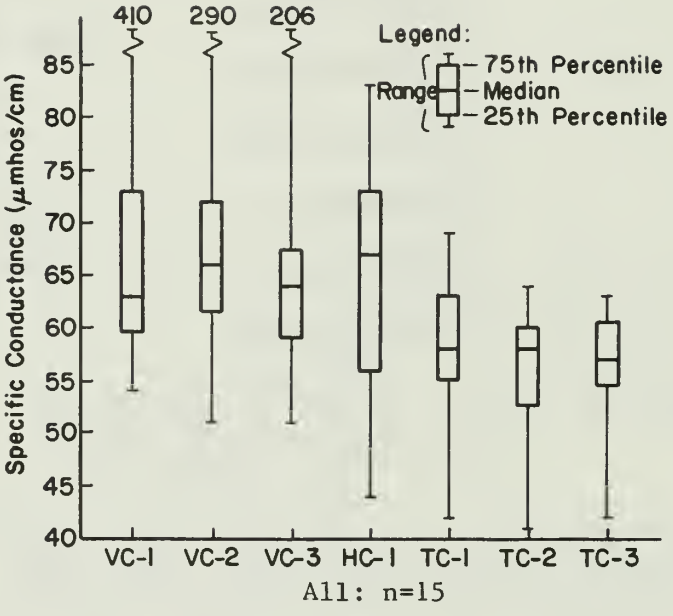

Figure 35. Median and range of specific conductance values for sampling sites in the Turkey Creek Unit (1975-1980). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Commander (1980).

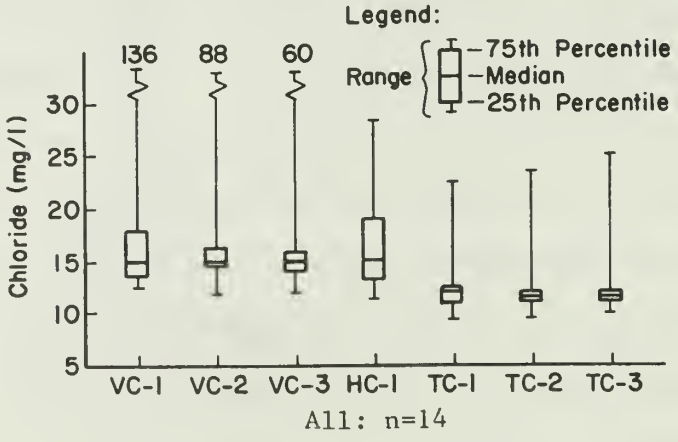

Figure 36. Median and range of chloride concentrations for sampling sites in the Turkey Creek Unit (1975-1980). Data taken from Harrel (1976, 1977), Harrel and Darville (1978), and Harrel and Commander (1980).

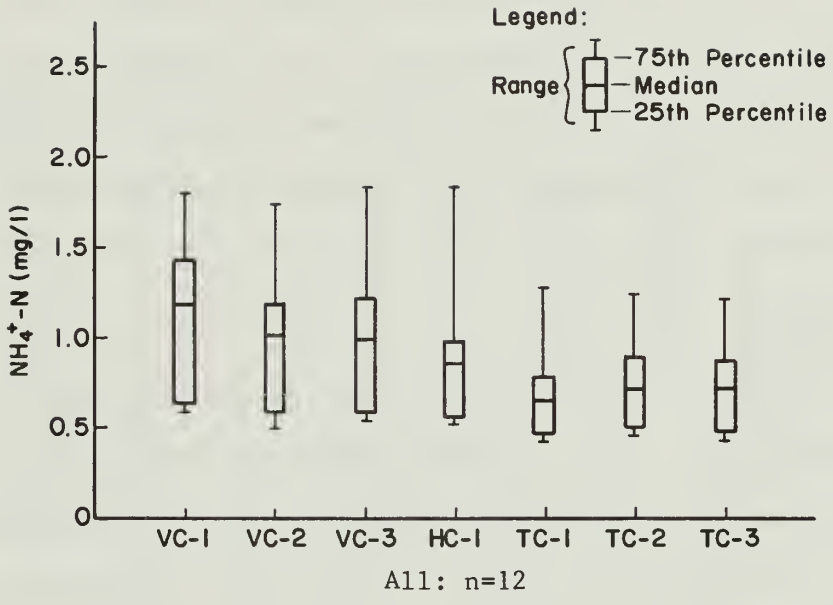

Figure 37. Median and range of NH_4^+-N concentrations for sampling sites in the Turkey Creek Unit (1979-1980). Data taken from Harrel and Commander (1980).

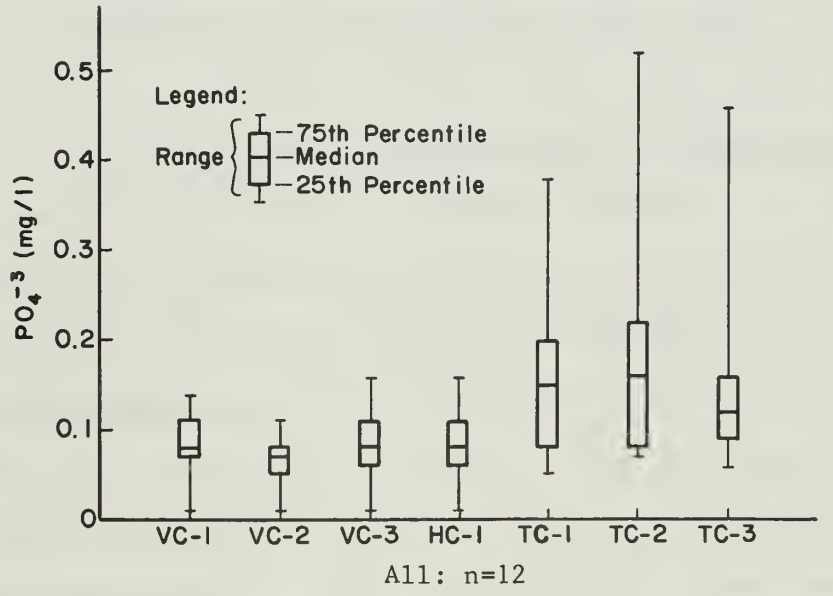

Figure 38. Median and range of PO_4^{-3} concentrations for sampling sites in the Turkey Creek Unit (1979-1980). Data taken from Harrel and Commander (1980).

medians ranged from 0.65 to 0.8 mg/l. The opposite is true for orthophosphate, where the highest concentrations occurred at the Turkey Creek sampling sites. No explanation is apparent for these relationships, though it should be noted that Village Creek drains a significantly larger watershed and has a greater mean annual flow than does Turkey Creek.

Biological Sampling

Fecal coliform and fecal streptococcus bacteriological data are presented in Figure 39. Fecal coliform bacterial levels generally met the state standard for Village Creek by not exceeding 200 organisms per 100 ml. As in Big Sandy Creek, moderate amounts of contamination were periodically reported, especially in Turkey Creek, indicating the possibility of sporadic contamination from improperly treated sewage. Also as in the case of Big Sandy Creek, fecal streptococcus bacterial levels were generally an order of magnitude higher than the fecal coliform levels, suggesting that the primary source of contamination may be warm-blooded animals other than humans. Bacterial counts generally increased during periods of high runoff and discharge.

Individuals representing 134 taxa of benthic macroinvertebrates were collected and identified from the seven sampling sites. Annually the segmented worms (Oligochaeta) and true flies (Diptera) were the most abundant organisms at all sites (Figure 40). No seasonal trends were apparent with respect to taxa or number of individuals. The numbers collected increased following floods due to scouring of the stream bottom substrate (Harrel and Commander, 1980). Shannon-Weaver species diversity values were considerably lower than the diversity values at the Big Sandy Creek and Beech Creek Units.

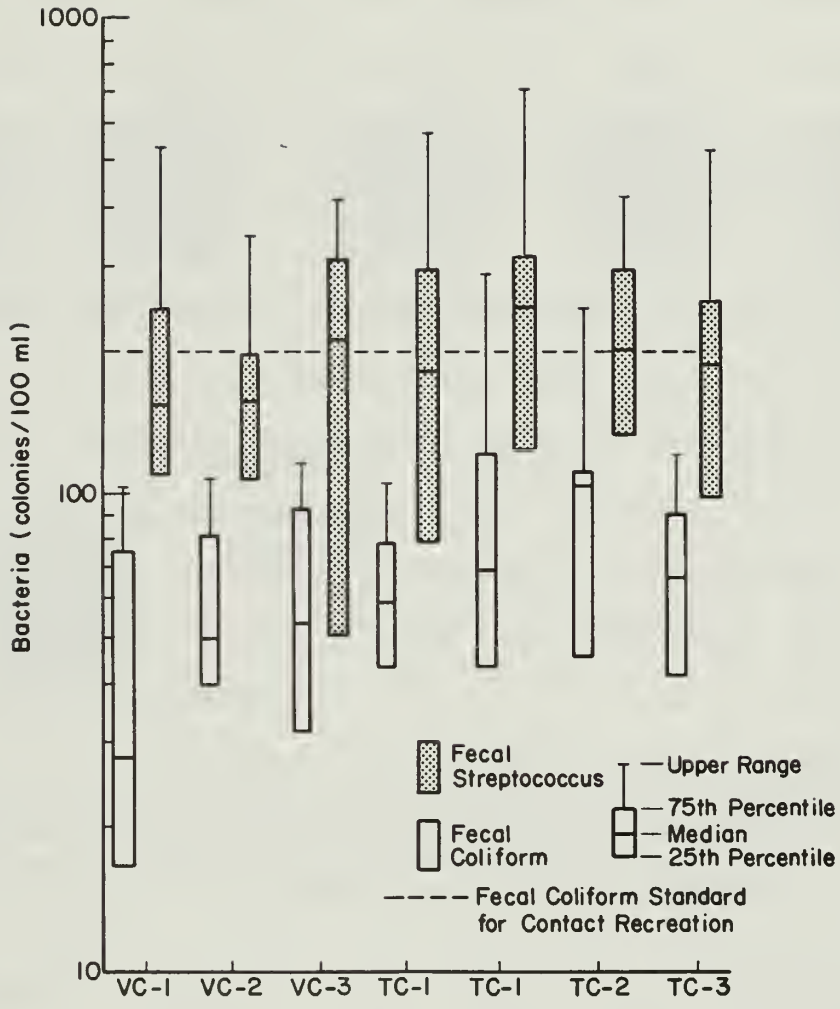

Figure 39. A profile of fecal coliform and fecal streptococcus bacteria counts through the Turkey Creek Unit (1979-1980). Data taken from Harrel and Commander (1980).

Fish populations were not sampled in the section of Village Creek that flows into the Turkey Creek Unit. However, in Turkey Creek, Suttkus and Clemmer (1978) collected one species each of lamprey, pike, sucker, killifish, livebearer, silverside, and pirateperch, two species of catfish, five species of perch, nine species of minnows, and eleven species of sunfish.

Hickory Creek produced a similar collection of fish: one species each of lamprey, pike, killifish, livebearer, silverside, and pirate-

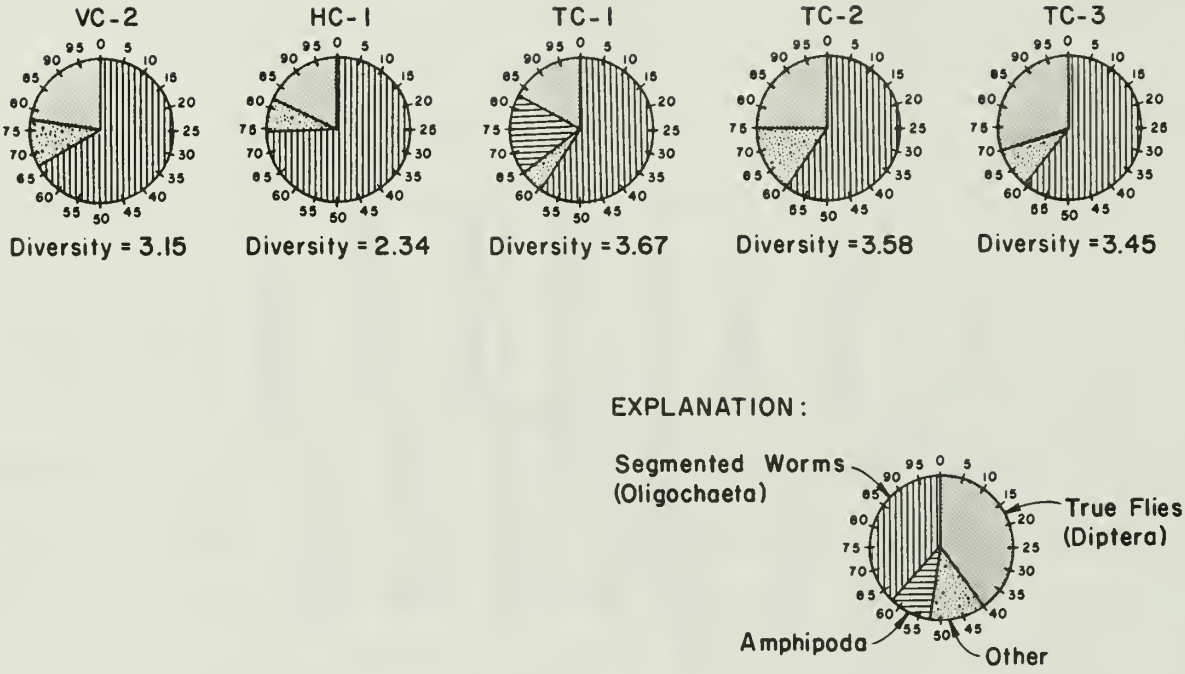

Figure 40. Annual percent distribution of aquatic macroinvertebrates and Shannon-Weaver diversity values for some sampling sites in the Turkey Creek Unit (1979-1980). Data taken from Harrel and Commander (1980).

perch, two species of sucker, three species of catfish, five species of perch, eight species of sunfish, and ten species of minnow.

Conclusions

The results of Harrel and Commander's August 1979 through July 1980 study of Turkey Creek indicate that physicochemical water quality conditions are very good. Dissolved oxygen saturation usually was greater than 80 percent and did not indicate any significant degradation from upstream discharge of treated sewage effluent. However, projected increases of wasteloading between 1980 and 2000 (Lower Neches Valley Authority, 1978) are a concern and should be monitored by NPS.

Alkalinity, pH, turbidity, and apparent color all fall within the normal range for streams of the Big Thicket. Specific conductance and chloride levels were occasionally high in Village Creek, presumably due to oil field activities within its watershed. No increases in specific conductance or chloride concentration were detected in Turkey Creek, but these constituents should be closely monitored by NPS because of the significant amount of oil field activity in the unit.

Nutrient concentrations generally lie within the expected range for undisturbed waters of the southeastern Texas Gulf Coast. Ammonium levels were higher in Village Creek than in Turkey Creek, possibly because of differences in watershed characteristics or increased treatment plant waste load.

Bacterial contamination was generally slight in Turkey Creek. Nonetheless, occasional samples failed to meet state standards for contact recreation. Continued bacteriological monitoring is recommended as contact recreational activity on Turkey Creek increases.

Harrel and Commander (1980) reported benthic macroinvertebrate diversity index values that were lower in the Turkey Creek Unit than diversity index values reported in previous studies of Big Sandy Creek and Beech Creek. The lower diversity (generally a sign of stressed biological conditions) may be due to less favorable substrate conditions in Turkey Creek or the impact of oil field brines on invertebrate communities of Village Creek.

LITERATURE CITED

Bass, D. G. 1979. Physicochemical conditions, fecal bacteria and benthic macroinvertebrates of Menard Creek in the Big Thicket National Preserve. M.S. thesis, Lamar University, Beaumont, Texas. 66 p.

Darville, R. G. 1978. Water quality in Little Pine Island and Pine Island Bayous in the Big Thicket National Preserve. M.S. thesis, Lamar University, Beaumont, Texas. 74 p.

Deshotels, J. D. 1978. Soil survey of Big Thicket National Preserve. U.S. Dept. of Agriculture, Soil Conservation Service, in cooperation with the National Park Service and the Texas Agricultural Experiment Station. 233 p.

Harrel, R. C. 1976. Preliminary limnological survey of streams in the Big Thicket National Preserve. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7000-5-0770. 46 p.

Harrel, R. C. 1977. Water quality monitoring in the Big Thicket National Preserve. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-6-0846. 38 p.

Harrel, R. C., and D. Bass. 1979. Water quality monitoring in the Big Thicket National Preserve. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-8-0789. 65 p.

Harrel, R. C., and S. D. Commander. 1980. Water quality monitoring in the Big Thicket National Preserve, Turkey Creek Unit. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7140-9-0199. 87 p.

Harrel, R. C., and R. G. Darville. 1978. Water quality monitoring in the Big Thicket National Preserve. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-7-0636. 100 p.

Harrel, R. C., and W. Newberry. 1981. Water quality monitoring in the Big Thicket National Preserve, Big Sandy Creek Unit. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-1-0144. 68 p.

Harrel, R. C., and G. Watson. 1975. Limnological and hydrological research in the Big Thicket National Preserve area, problems posed, and recommendations for additional research. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7000-5-0475. 19 p.

Kost, D. 1977. Physicochemical conditions and macrobenthos of streams in the Beech Creek Unit of Big Thicket National Preserve. M.S. thesis, Lamar University, Beaumont, Texas. 62 p.

Lower Neches Valley Authority. 1978. Water Quality Management Plan for the Lower Neches River Basin, Vol. II. Prepared pursuant to the requirement of Section 208 of the Federal Water Pollution Control Act Amendments of 1972. 370 p.

Suttkus, R. D., and G. H. Clemmer. 1979. The fishes of the Big Thicket National Preserve. Contracted through C. Jones, Director of Bird and Mammal Laboratory for National Museum of Natural History. U.S. Fish and Wildlife Service, Tulane University, and Mississippi State University, Starkville, Mississippi.

Texas Department of Water Resources. 1981. Texas surface water quality standards. Austin, Texas. 107 p.

Trenchard, M. 1977. Baseline climatological study of Big Thicket National Park. Texas A&M University, College Station, Texas.

U.S. Department of the Interior. 1976. Final environmental statement: Establishment of Big Thicket National Preserve, Texas. National Park Service, Washington, D.C. 323 p.

APPENDIX

Annotated Bibliography of Hydrology and Water Quality Studies: Big Thicket National Preserve, Texas

Adsit, W. H., and L. R. Hagen. 1978. Intensive surface water monitoring survey for Segment 0607 (Pine Island Bayou). Texas Department of Water Resources, Austin, TX. 46 p.

An intensive monitoring survey was conducted on Pine Island Bayou, in the Big Thicket region of southeastern Texas, during the months of October and November, 1975, and July, 1976. Hydrological, biological, and physicochemical data were collected and analyzed. Water quality conditions were found to be generally poor. Discussion of water quality problems, including a description of numerous point and nonpoint pollution sources found in the vicinity of Segment 0607, indicates some cause-effect relationships of water quality in Pine Island Bayou.

American Petroleum Institute. 1982. Analysis of hydrologic and environmental effects of drilling mud pits and produced water impoundments, Volume I: Executive summary and report. 104 p.

This study, prepared by the consulting firm of Dames & Moore of Houston, Texas, investigates the leaching potential of possible hazardous constituents from selected oil and gas field drilling mud reserve pits and emergency produced water impoundments. The eight study sites selected represented three major hydrogeologic regions, each with different potentials for leachate migration and detection, and current industry practices for operation, maintenance, and/or closure of mud pits and produced water impoundments. Of particular focus in the study were 1) possible transport pathways of leached constituents, and 2) the quantity of leach constituents and their toxicity, if any, to humans or the environment. Various chemical parameters were measured including the seven heavy metals for which concentration standards have been set. Findings indicate no significant threat to either human health or environmental integrity from these two drilling facilities.

Bass, D. 1979. Physicochemical conditions, fecal bacteria, and benthic macroinvertebrates of Menard Creek in the Big Thicket National Preserve. M.S. thesis, Lamar Univ., Beaumont, TX. 65 p.

Water quality of Menard Creek was studied from July, 1978, to June, 1979, utilizing physicochemical parameters, bacteriological data, and benthic macroinvertebrates. Water samples were collected on a monthly basis at five monitoring stations. Benthic macroinvertebrates were collected seasonally by way of dredge samples. Although

physicochemical conditions indicated generally good water quality, numbers of fecal bacteria were higher than acceptable at all stations during much of the study period, especially after heavy rains and subsequent surface runoff.

Blakey, J. F., and H. L. Kunze. 1971. Reconnaissance of the chemical quality of surface waters of the coastal basins of Texas. Texas Water Development Board, Austin, TX. 49 p.

This report presents available data and interpretations on the quality of surface waters of the eight Texas coastal basins. The basins comprise 19,000 square miles of Gulf Coast area, with some drainage areas extending more than 100 miles inland. In consideration of proper development, management, and use of water resources of this extensive area, the following factors were examined in this study: the nature and concentrations of mineral constituents in solution; the geologic, hydrologic, and cultural influences that determine water quality; and the suitability of the water for municipal supply, industrial use, and irrigation. Each basin is discussed in detail vis-a-vis natural features, water quality, and influential human activity, accompanied by numerous tables and maps. The various maps show geology, precipitation and moisture regions, oil fields, irrigation areas, and collection site locations.

Commander, S. D. 1978. An evaluation of the fecal coliform loads and in-stream densities of coliform organisms in Pine Island Bayou. Lower Neches Valley Authority Technical Department, Report No. 78-3. 77 p.

This study was designed to ascertain if Pine Island Bayou could maintain its fecal coliform standard of 200 organisms/100 ml during high flow and low flow conditions and to identify sources of fecal coliform contamination. Fecal coliform and fecal streptococcus organisms were analyzed at 12 stream stations twice each week for two 30-day periods, January through February, 1978 and April through May, 1978. All wastewater treatment plants were monitored for fecal coliform and fecal streptococcus once each week for each 30-day period. Data were analyzed and then assessed for compliance with set water quality standards. All stations were in violation of the fecal coliform stream standard during the first monitoring period, and five were in violation, though not by as much, during the second. It was found that stormwater runoff contributes significantly more fecal coliform loading to Pine Island Bayou waters than all wastewater treatment plants combined, due in one case to local septic tank use. Recommendations for further study and monitoring are included.

Darville, R. C. 1978. Water quality in Little Pine Island and Pine Island Bayous in the Big Thicket National Preserve. M.S. thesis, Lamar Univ., Beaumont, TX. 74 p.

Water quality of Pine Island and Little Pine Island Bayous in the Big Thicket National Preserve of Southeast Texas was studied from June, 1977 to May, 1978 utilizing physicochemical parameters, bacteriological data, and benthic macroinvertebrates. Data were collected from seven monitoring stations along the waterway segment studied. Physicochemical conditions generally indicated good water quality. However, numbers of fecal bacteria surpassed accepted levels at each station on at least one occasion. Highest numbers were generally found after heavy rains and subsequent surface runoff. Of benthic macroinvertebrates, 123 taxa and 15,263 individuals were collected. Oligochaetes and chironomids dominated. Variation by station was attributed to similarities or differences in physicochemical conditions, substrates, and discharge.

Harrel, R. C. 1976. Preliminary limnological survey of streams in the Big Thicket National Preserve. U.S. Department of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7000-5-0770. 46 p.

This study was undertaken to determine locations for the establishment of water quality monitoring stations in BITH; to obtain preliminary water quality data from streams within BITH; to locate existing or potential sites of water pollution and stress that may influence management practices; and to develop recommendations for future investigations. Field work was performed between May and October, 1975. Physicochemical data were collected from the six smaller stream systems of Beech Creek, Turkey Creek, Hickory Creek, Village Creek, Big Sandy Creek, Menard Creek, and Little Pine Island Bayou. Benthic macroinvertebrates were collected from one station in Beech Creek. All data collection was complicated by unusually high rainfall and stream flooding during the study period and took place on a random basis as accessibility to monitoring stations allowed. Thus, neither downstream physicochemical trends nor sites and sources of stress could be determined. Additional data was obtained from three local agencies. The need for regular and continuous monitoring (to cover seasonal changes and conditions) is stressed. Maps depicting the locations of monitoring stations are included.

Harrel, R. C. 1977. Water quality monitoring in the Big Thicket National Preserve. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-6-0846. 38 p.

This paper tabulates comprehensive water quality data for use as a baseline measure for streams in the Beech Creek, Turkey Creek, Big

Sandy Creek, and Lance Rosier and Menard Creek Corridor Units. Physicochemical and biological samples were collected between May 5 and December 22, 1976. Data were analyzed to 1) determine downstream trends, 2) locate existing and potential sites of pollution, and 3) develop recommendations for management within the preserve.

Harrel, R. C., and D. Bass. 1979. Water quality monitoring in the Big Thicket National Preserve. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-8-0789. 65 p.

This study presents and analyzes water quality data from the Menard Creek Corridor. Data were collected from five monitoring stations in the corridor from July, 1978 through June, 1979. Physicochemical and biological parameters are examined. This study served as the basis of D. Bass's Master's thesis (1979), cited earlier in this bibliography.

Harrel, R. C., and S. D. Commander. 1980. Water quality monitoring in the Big Thicket National Preserve, Turkey Creek Unit. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7140-9-0199. 87 p.

From August, 1979 through July, 1980, water quality data were collected from seven sampling stations in the Turkey Creek Unit of BITH. Three were located on Village Creek, three were on Turkey Creek itself, and one was on Hickory Creek. Physicochemical conditions were monitored and fecal coliform and fecal streptococci numbers were determined monthly, while benthic macroinvertebrates were collected seasonally. During each sampling period stream height was measured. Despite five permitted waste discharges in watersheds upstream from the Turkey Creek Unit, physicochemical conditions were generally excellent and bacterial contamination slight. A lengthy bibliography and comprehensive tabular data are included.

Harrel, R. C., and R. G. Darville. 1978. Water quality monitoring in the Big Thicket National Preserve. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-7-0636. 100 p.

This paper combines the Master's thesis of R. G. Darville (1978) as Part I, and Water Quality of Streams in the Beech Creek, Turkey Creek, and Big Sandy Creek Units and Menard Creek Corridor as Part II. For Part I, see reference cited under R. G. Darville. Part II describes the collection and analysis of water quality data (including physicochemical and biological parameters) from five sampling stations on Beech Creek, eight stations in the Turkey Creek unit, five stations on Big Sandy Creek, and five stations in

the Menard Creek Corridor. Data were collected from the various units between mid-June and mid-August, 1977. Data are presented in tabular form, followed by a synthesis of findings and recommendations for future research and management.

Harrel, R. C., and T. C. Dorris. 1968. Stream order, morphometry, physico-chemical conditions, and community structure of benthic macroinvertebrates in an intermittent stream system. Amer. Midl. Nat. 80:220-251.

Morphometry, physicochemical conditions, and community structure of macrobenthos are quantitatively related to stream order in a sixth order intermittent stream system (Otter Creek drainage basin) in north-central Oklahoma. Numbers of species and individuals, and species diversity and heterogeneity indices were used as measures of community structure. Twenty-one sampling stations were used along nine streams of different orders in the drainage basin. All sampling was done monthly from June, 1964 to May, 1965. Weather conditions (precipitation and periods of drought) and seepage from oil-field brines were found to upset the stream order-community structure relationship.

Harrel, R. C., and W. Newberry. 1981. Water quality monitoring in the Big Thicket National Preserve, Big Sandy Creek Unit. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7029-1-0114. 68 p.

This paper examines water quality in yet another BITH water corridor, Big Sandy Creek. Water quality data, including physicochemical data, bacteria, and benthic macroinvertebrates, were collected from five monitoring stations in the Big Sandy Creek Unit. Big Sandy stands out from other BITH water units in that all parameters measured fell within ranges expected for clean water streams in southeast Texas. Bacterial contamination was only slight, indicating safe conditions for contact recreation. An extensive bibliography is included in this paper, and tabular presentation of data is likewise comprehensive.

Harrel, R. C., and G. Watson. 1975. Limnological and hydrological research in the Big Thicket National Preserve area, problems posed, and recommendations for additional research. U.S. Dept. of the Interior, National Park Service, Southwestern Region. Research Project Report, Contract No. PX7000-5-0475. 19 p.

This report summarizes limnological and hydrological research done prior to 1975 in the vicinity of BITH. Special hydrological problems associated with area land use impact are discussed, including

oil field development, increased housing development, tree farms, clear cutting, and salt water intrusion. Recommendations for future research and an extensive bibliography complete the report.

Keeton, D. 1959. Limnological effects of introducing oil field brines into farm ponds to reduce turbidity. Oklahoma Fishery Research Laboratory, Report No. 72. 47 p.

In this study, oil field brines were added to two turbid farm ponds in Hughes County, Oklahoma, and the effects on biota and physico-chemical conditions assessed. Brine was added in small amounts to one pond at weekly and biweekly intervals (intermittent introduction), and to a second pond in a single application (large, single introduction). A third pond served as a control. The comparative action of the brine and its effects upon the biological, chemical, and physical properties (especially turbidity) of the two ponds are documented and discussed. Limnological conditions during and after the introductions are also considered, including the effects of rainfall, subsequent runoff, and seasonal cycles. In general, the introduction of brines into ponds to reduce turbidity is recommended; but intermittent introduction during any season is shown to be safer than a large, single application which may harm the biota.

Keup, L. E., W. M. Ingram, and K. M. Mackenthun. 1966. The role of bottom-dwelling macrofauna in water pollution investigations. U.S. Dept. of Health, Educ., and Welfare, Cincinnati, OH. 23 p.

The authors evaluate the use of bottom-dwelling animals in water pollution abatement programs. How and why the bottom-dwelling fauna exhibit pollution-induced changes and the factors involved in data collection, interpretation, and evaluation are discussed. A bibliography on the theory and applied use of bottom-dwelling animals in pollution evaluation is included.

Kost, D. 1977. Physicochemical conditions and macrobenthos of streams in the Beech Creek Unit of the Big Thicket National Preserve. M.S. thesis, Lamar Univ., Beaumont, TX. 62 p.

Physicochemical conditions and community structure of benthic macroinvertebrates in the streams of the Beech Creek Unit of BITH were studied from May, 1976 to April, 1977. Water samples were collected from five sampling stations on a monthly basis, and benthic macroinvertebrates were sampled bimonthly at the same stations. Physicochemical measurements identified no significant sources of pollution; lumbering within and outside the unit had no apparent effects on macrobenthic community structure. Extremes of chemical parameters usually correlated with extremes in discharge or temperature.

Lewis, S. P. 1974. Physicochemical conditions and macrobenthos of Village Creek, Texas. M.S. thesis, Lamar Univ., Beaumont, TX. 43 p.

Lewis, S. P., and R. C. Harrel. 1978. Physicochemical conditions and diversity of macrobenthos of Village Creek, Texas. Southwest Nat. 23(2):263-272.

These two writings refer to the same study: the Lewis and Harrel article is a condensed and polished version of Lewis' Master's thesis. Therefore, they are being treated as one for annotation purposes.

Physicochemical conditions and benthic macroinvertebrates were studied in Village Creek, a southeast Texas clean water stream flowing through BITH. Monthly determinations were made at six sampling stations from July, 1972 through July, 1973. Benthic macroinvertebrates were collected during August, October, and December, 1972 and April and July, 1973. Physicochemical conditions and benthic community structure are discussed with respect to discharge fluctuations, season, and stream location. Findings contradicted the concept of high diversity-high environmental stability.

Lower Neches Valley Authority. 1983. Development and assessment of alternative management practices. Pine Island Bayou Water Quality Management Study Task 0607.334. Texas Department of Water Resources, Austin, TX.

This report investigates alternative management strategies for control of nonpoint sources of organic, bacteriological, and brine pollution in the Pine Island Bayou watershed. Results of data analysis in this report, taken together with that of the Nonpoint Source Study (annotated below), suggest only one alternative strategy. This one is presented as a series of steps related to dissolved oxygen, fecal coliform, and chloride problem sources. Fecal coliform data indicated violations of water quality standards on the mainstem for contact recreation, and eight of twelve tributary stations violated standards for noncontact recreation in over 25 percent of the samples collected. Recommendations are made for continued water quality management with respect to these violations and the as yet undetermined cause-effect relationship between pollutant sources and bacteriological problems.

Lower Neches Valley Authority. 1983. Nonpoint source study: Segment 0607 (Pine Island Bayou). Data appendices C and D. Texas Dept. of Water Resources, Austin, TX. Contract No. 14-20037.

This two-volume study reports on the design and implementation of a sampling and testing program of nonpoint sources of pollution in the Pine Island Bayou watershed in BITH. The first volume contains the study description and data analysis; the second volume, Appendices C and D, includes raw data collected throughout the study period, quality assurance data, and several maps giving reference to land uses and to point and nonpoint pollution sources in the basin. The study addresses the relationship between nonpoint sources and water quality problems in Pine Island Bayou. Both a wet weather and a dry weather monitoring program were used. Specific attention was given to: 1) the effects of urban and forest land stormwater runoff; 2) the loading from septic tanks during stormwater runoff; 3) the origin of elevated fecal coliform levels during runoff; 4) the sources of chlorides; and 5) values of dissolved oxygen concentrations. Recommendations are given for future data analysis.

Mathis, B. J., and T. C. Dorris. 1968. Community structure of benthic macroinvertebrates in an intermittent stream receiving oil field brines. Amer. Midl. Nat. 80:428-439.

Physicochemical conditions and community structure of benthic macroinvertebrates in an oil field brine-polluted stream in Oklahoma were studied from October, 1963 to September, 1964. Samples were collected from seven monitoring stations on a monthly basis. Data were analyzed with attention given to the relationship between the parameters measured and differential effects of oil field brines and domestic and oil refinery effluents. Turbidity was found to vary inversely with conductivity and was lowest where brines were more highly concentrated. In addition, maximum numbers of individual species occurred where turbidity was lowest.

Tatum, J. W., and D. Commander. 1971. Water quality study of Village Creek, Hardin County, Texas. Texas Water Quality Board. Mimeo. 40 p.

This study of Village Creek was conducted in March and May, 1971. Data were collected and analyzed for physicochemical quality, bacteriological quality, and the community structure of benthic macroinvertebrates. The six sampling stations used were located on the river segment from above Village Mills to the confluence of Village Creek and the Neches River. In addition, effort was made to test the effluents of all municipalities and industries in the Village Creek watershed during the study period. These analyses show little organic load placed on the stream and its tributaries.

Texas Department of Water Resources. 1962. Drainage areas of Texas streams, Neches River Basin and Neches-Trinity coastal area. Circular No. 62-03. October, 1962.

This report compiles and presents drainage-area information of uniform accuracy and reliability. It is intended for all hydraulic, hydrologic, or general engineering use.

Texas Department of Water Resources. 1978. Projected land use maps, year 2000: Neches Basin. Austin, TX. LP-054.

Color maps of various aspects of projected land use for the Neches River Basin.

Texas Department of Water Resources. 1981. Texas Surface Water Quality Standards. Austin, TX. 116 p.

This document contains the most current revision of Water Quality Requirements, developed by the Texas Water Quality Board in 1967.

Texas Water Development Board. 1966. A summary of the preliminary plan for proposed water resources development in the Neches River Basin. Austin, TX. 77 p.

Prepared as an integral part of the Texas Water Plan, this preliminary Neches River basin plan has as its objective determination of long-range (to year 2020) in-basin water requirements and suggested development of available water resources to meet such requirements. The plan provides for fulfilling the projected 2020 basin water requirements along with providing a surplus basin yield in excess of those requirements and exports. Attention is given to amount, quality, and use of surface and groundwater supply. Flood and hurricane damage is also considered in the plan.

U.S. Department of the Interior. 1976. Final environmental statement: Establishment of Big Thicket National Preserve, Texas. National Park Service, Washington, D.C. 323 p.

This is the environmental impact statement (EIS) completed for the establishment of Big Thicket as a National Preserve. Of particular interest is Section II, Description of the Environment, which provides an overall description of the area as well as individual descriptions of the 12 units that constitute the preserve. The statements on hydrology and on water quality (under Section III, Environment Impacts of the Actions) are brief. The accompanying maps, bibliography, and appendices offer useful information regarding local flora and fauna.

Wilhm, J. L. 1967. Comparison of some diversity indices applied to populations of benthic macroinvertebrates in a stream receiving organic wastes. Jour. WPCF 39(10):1673-1683.

Here the author examines the use of benthic community measures as a means of determining pollution in a stream receiving organic enrichment. Discussion includes a helpful analysis of species diversity indices. The Skeleton Creek drainage basin study (Wilhm and Dorris, 1966) provides the data base. In the conclusion, note is made of recommended sampling methodology and data analysis.

Wilhm, J. L., and T. C. Dorris. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. Amer. Midl. Nat. 76:427-449.

This is a study of physicochemical conditions and benthic macroinvertebrate community structure in a stream receiving domestic and oil refinery effluents. Skeleton Creek in Oklahoma is the study site along which eight sampling stations were used for data collection. Samples were collected monthly from March, 1963 to March, 1964. In evaluating and discussing the data, the authors note that measures derived from information theory (diversity per individual and redundancy) were found to be more precise measures of stream conditions, as reflected by macrobenthos populations, than traditional methods.

Wilhm, J. L., and T. C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience 18:477-481.

In this paper the authors discuss and evaluate various concepts and methods of water quality analysis. Based on this examination, their recommendation is to establish water quality criteria by evaluating biological conditions in receiving streams. They argue that because of the striking changes effluents cause in benthic community structure, pollution - or a return to normal stream conditions - is readily apparent in a longitudinal study of macrobenthos.